Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	0	Manual	
679994.969	3082983.51	J-48S	0	Manual	
680057.658	3083072.075	J-49S	0	Manual	
680077.354	3083115.533	J-50S	0	Manual	
679827.115	3082729.746	J-51S	0	Manual	
680141.873	3083080.88	J-52S	0	Manual	
680170.56	3083064.674	J-53S	0	Manual	

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Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679530.943	3082575.448	G-36SD	0	Manual	
679606.684	3082692.383	G-37SD	0	Manual	
679671.317	3082565.925	G-46SD	0	Manual	
679745.982	3082681.386	G-47SD	0	Manual	
679521.779	3082672.022	J-54SD	0	Manual	
680108.013	3083101.352	J-57SD	0	Manual	
680413.831	3083297.013	J-58SD	0	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679638.466	3083412.561	G-21SD	0	Manual	
679715.315	3083530.019	G-22SD	0	Manual	
679789.831	3083644.936	G-23SD	0	Manual	
679780.111	3083404.025	G-24SD	0	Manual	
679854.225	3083519.822	G-25SD	0	Manual	
679931.397	3083636.406	G-26SD	0	Manual	
679393.438	3082582.947	G-27SD	0	Manual	
679470.286	3082698.021	G-28SD	0	Manual	
679543.314	3082816.106	G-29SD	0	Manual	
679619.124	3082932.898	G-30SD	0	Manual	
679693.405	3083047.549	G-31SD	0	Manual	
679768.226	3083162.727	G-32SD	0	Manual	
679841.774	3083280.235	G-33SD	0	Manual	
679917.766	3083397.416	G-34SD	0	Manual	
679994.207	3083513.447	G-35SD	0	Manual	
679530.943	3082575.448	G-36SD	0	Manual	
679606.684	3082692.383	G-37SD	0	Manual	
679681.465	3082807.799	G-38SD	0	Manual	
679756.109	3082922.939	G-39SD	0	Manual	
679832.158	3083041.871	G-40SD	0	Manual	
679906.421	3083156.754	G-41SD	0	Manual	
679982.277	3083273.065	G-42SD	0	Manual	
680056.981	3083387.33	G-43SD	0	Manual	
680132.65	3083505.456	G-44SD	0	Manual	
679597.188	3082450.923	G-45SD	0	Manual	
679671.317	3082565.925	G-46SD	0	Manual	
679745.982	3082681.386	G-47SD	0	Manual	
679822.074	3082799.575	G-48SD	0	Manual	
679896.612	3082915.666	G-49SD	0	Manual	
679971.215	3083030.792	G-50SD	0	Manual	
680046.783	3083146.999	G-51SD	0	Manual	
680123.432	3083263.001	G-52SD	0	Manual	
680198.058	3083379.815	G-53SD	0	Manual	
680185.412	3083138.847	G-54SD	0	Manual	
680260.421	3083254.807	G-55SD	0	Manual	
680335.97	3083372.02	G-56SD	0	Manual	
680022.008	3083237.472	J-44SD	0	Manual	
680047.095	3083215.942	J-45SD	0	Manual	
679887.433	3082812.936	J-46SD	0	Manual	
679521.779	3082672.022	J-54SD	0	Manual	
679590.092	3082773.184	J-55SD	0	Manual	
679763.399	3083050.055	J-56SD	0	Manual	
680108.013	3083101.352	J-57SD	0	Manual	
680413.831	3083297.013	J-58SD	0	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	0	Manual	
679994.969	3082983.51	J-48S	0	Manual	
680057.658	3083072.075	J-49S	0	Manual	
680077.354	3083115.533	J-50S	0	Manual	
679827.115	3082729.746	J-51S	0	Manual	
680141.873	3083080.88	J-52S	0	Manual	
680170.56	3083064.674	J-53S	0	Manual	

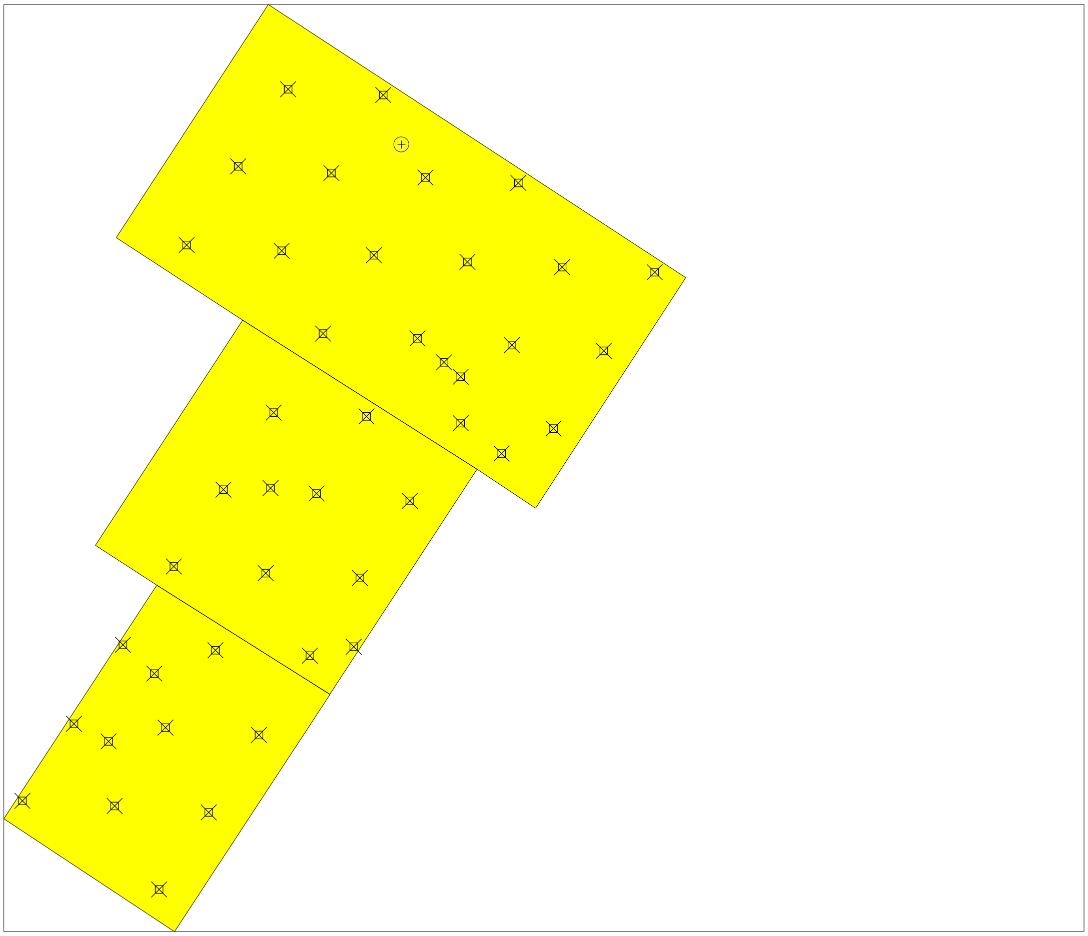
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	15
Number of samples on map [a]	44
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$8,500.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
679638.4660	3083412.5610	G-21SD	971	Manual	T
679715.3150	3083530.0190	G-22SD	34700	Manual	T
679789.8310	3083644.9360	G-23SD	35900	Manual	T
679780.1110	3083404.0250	G-24SD	2600	Manual	T
679854.2250	3083519.8220	G-25SD	5490	Manual	T
679931.3970	3083636.4060	G-26SD	6525	Manual	T
679841.7740	3083280.2350	G-33SD	3810	Manual	T
679917.7660	3083397.4160	G-34SD	4560	Manual	T
679994.2070	3083513.4470	G-35SD	2220	Manual	T
679982.2770	3083273.0650	G-42SD	1080	Manual	T
680056.9810	3083387.3300	G-43SD	13400	Manual	T
680132.6500	3083505.4560	G-44SD	1790	Manual	T
680046.7830	3083146.9990	G-51SD	2060	Manual	T
680123.4320	3083263.0010	G-52SD	1900	Manual	T
680198.0580	3083379.8150	G-53SD	5000	Manual	T
680185.4120	3083138.8470	G-54SD	2870	Manual	T

680260.4210	3083254.8070	G-55SD	12300	Manual	T
680335.9700	3083372.0200	G-56SD	2750	Manual	T
680022.0080	3083237.4720	J-44SD	1205	Manual	T
680047.0950	3083215.9420	J-45SD	1960	Manual	T
680108.0130	3083101.3520	J-57SD	14500	Manual	T
679958.5608	3083562.3366	G-30SD	2010	Random	

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679619.1240	3082932.8980	G-30SD	2010	Manual	T
679693.4050	3083047.5490	G-31SD	1670	Manual	T
679768.2260	3083162.7270	G-32SD	2860	Manual	T
679756.1090	3082922.9390	G-39SD	2060	Manual	T
679832.1580	3083041.8710	G-40SD	953	Manual	T
679906.4210	3083156.7540	G-41SD	2860	Manual	T
679822.0740	3082799.5750	G-48SD	10900	Manual	T
679896.6120	3082915.6660	G-49SD	2330	Manual	T
679971.2150	3083030.7920	G-50SD	1180	Manual	T
679887.4330	3082812.9360	J-46SD	5590	Manual	T
679763.3990	3083050.0550	J-56SD	2180	Manual	T

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679393.4380	3082582.9470	G-27SD	2390	Manual	T
679470.2860	3082698.0210	G-28SD	6165	Manual	T
679543.3140	3082816.1060	G-29SD	1490	Manual	T
679530.9430	3082575.4480	G-36SD	11700	Manual	T
679606.6840	3082692.3830	G-37SD	10300	Manual	T
679681.4650	3082807.7990	G-38SD	5620	Manual	T
679597.1880	3082450.9230	G-45SD	4290	Manual	T
679671.3170	3082565.9250	G-46SD	23100	Manual	T
679745.9820	3082681.3860	G-47SD	10400	Manual	T
679521.7790	3082672.0220	J-54SD	18900	Manual	T
679590.0920	3082773.1840	J-55SD	4655	Manual	T

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this

site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

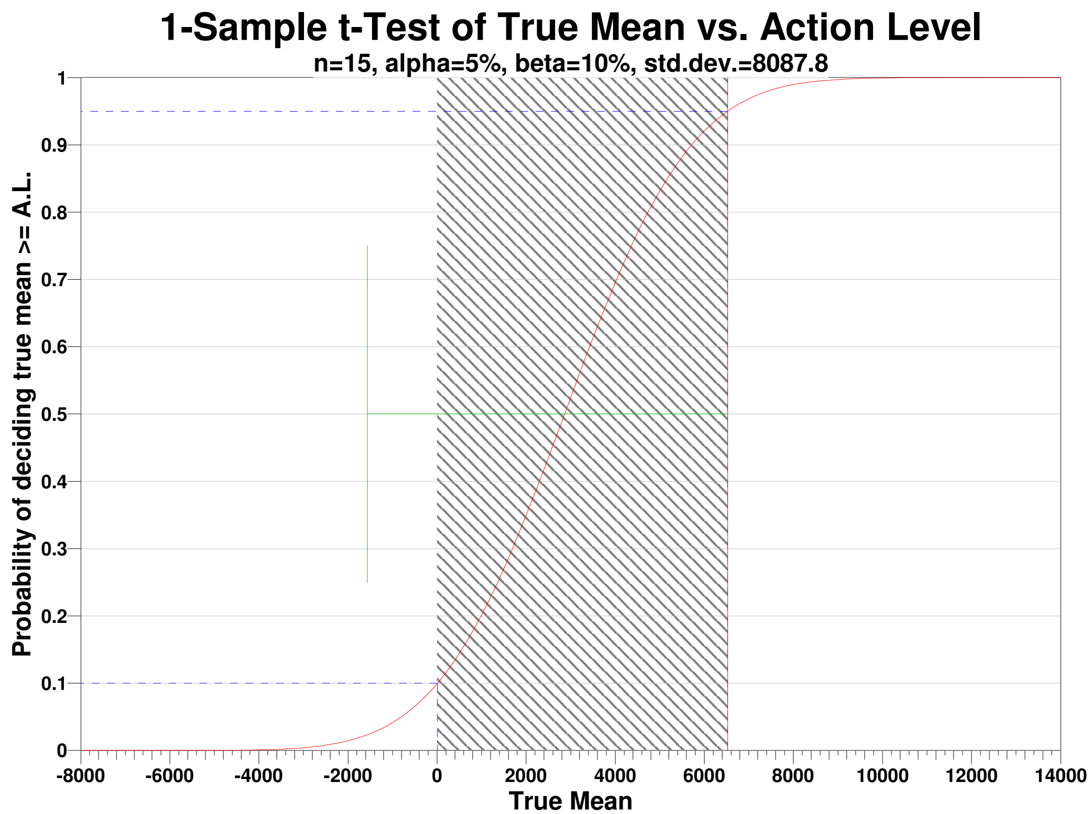
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	15	8087.8	6513.2	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=6521.2		α=5		α=10		α=15	
		s=16175.6	s=8087.8	s=16175.6	s=8087.8	s=16175.6	s=8087.8
LBGR=90	β=5	6660	1666	5270	1319	4424	1107
	β=10	5271	1319	4043	1012	3307	828
	β=15	4425	1108	3307	828	2645	662
LBGR=80	β=5	1666	418	1319	331	1107	277
	β=10	1319	331	1012	254	828	208
	β=15	1108	278	828	208	662	166
LBGR=70	β=5	742	187	587	148	493	124

	β=10	587	148	450	114	368	93
	β=15	493	125	369	93	295	74

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $8,500.00, which averages out to a per sample cost of $566.67. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**15 Samples**
Field collection costs		$100.00	$1,500.00
Analytical costs	$400.00	$400.00	$6,000.00
Sum of Field & Analytical costs		**$500.00**	**$7,500.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$8,500.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	1	2	3	4	5	6	7	8	9	10
0	953	971	1080	1180	1205	1490	1670	1790	1900	1960
10	2010	2010	2060	2060	2180	2220	2330	2390	2600	2750
20	2860	2860	2870	3810	4290	4560	4655	5000	5490	5590
30	5620	6165	6525	1.03e+004	1.04e+004	1.09e+004	1.17e+004	1.23e+004	1.34e+004	1.45e+004
40	1.89e+004	2.31e+004	3.47e+004	3.59e+004						

SUMMARY STATISTICS	
n	44
Min	953
Max	35900
Range	34947
Mean	6663.7
Median	2865
Variance	6.5412e+007
StdDev	8087.8
Std Error	1219.3
Skewness	2.3955
Interquartile Range	7346.3

Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
953	998.3	1193	2010	2865	9356	1.67e+004	3.18e+004	3.59e+004

Outlier Test
Rosner's test for multiple outliers was performed to test whether the most extreme value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

In using Rosner's test to detect up to 1 outlier, a test statistic R_1 is calculated, and compared with a critical value C_1 to test the hypothesis that there is one outlier in the data.

ROSNER'S OUTLIER TEST			
k	**Test Statistic R_k**	**5% Critical Value C_k**	**Significant?**
1	3.615	3.08	Yes

The test statistic 3.615 exceeded the corresponding critical value, therefore that test is significant and we conclude that the most extreme value is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
1	35900

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Rosner's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.7062
Shapiro-Wilk 5% Critical Value	0.943

The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the most extreme value, do not appear to follow a normal distribution at the 5% level of significance. Rosner's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

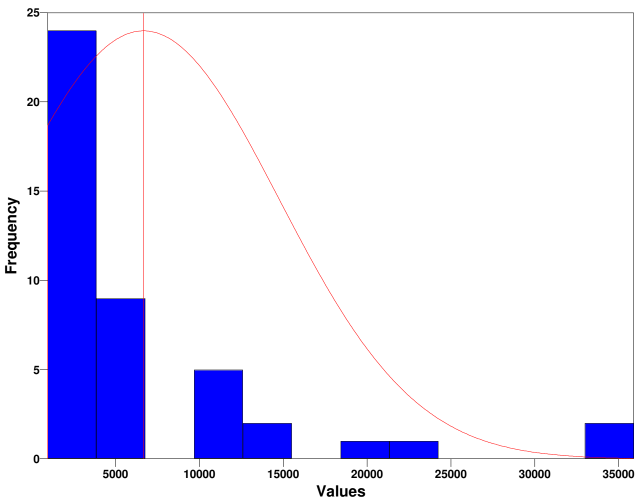
Data Plots
Graphical displays of the data are shown below.

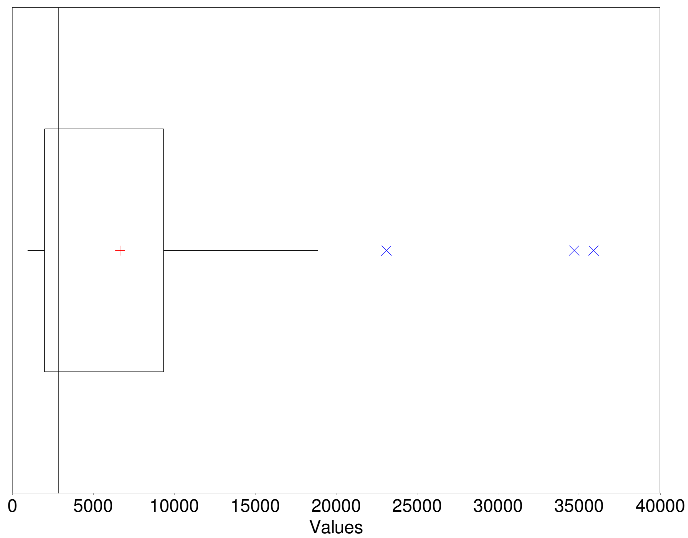
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

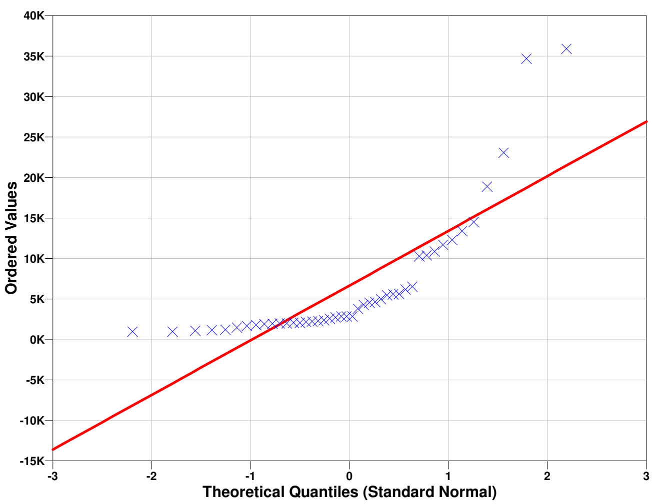
The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25^{th} and 75^{th} percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5

times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.6759
Shapiro-Wilk 5% Critical Value	0.944

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the

data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	8713
95% Non-Parametric (Chebyshev) UCL	1.198e+004

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (1.198e+004) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test

A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where

x is the sample mean of the n=44 data,
AL is the action level or threshold (6521.2),
SE is the standard error = (standard deviation) / (square root of n).

This t was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=43 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
0.1169	1.6811	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
32	27	Reject

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Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679638.466	3083412.561	G-21SD	971	Manual	
679715.315	3083530.019	G-22SD	34700	Manual	
679789.831	3083644.936	G-23SD	35900	Manual	
679780.111	3083404.025	G-24SD	2600	Manual	
679854.225	3083519.822	G-25SD	5490	Manual	
679931.397	3083636.406	G-26SD	6525	Manual	
679393.438	3082582.947	G-27SD	2390	Manual	
679470.286	3082698.021	G-28SD	6165	Manual	
679543.314	3082816.106	G-29SD	1490	Manual	
679619.124	3082932.898	G-30SD	2010	Manual	
679693.405	3083047.549	G-31SD	1670	Manual	
679768.226	3083162.727	G-32SD	2860	Manual	
679841.774	3083280.235	G-33SD	3810	Manual	
679917.766	3083397.416	G-34SD	4560	Manual	
679994.207	3083513.447	G-35SD	2220	Manual	
679530.943	3082575.448	G-36SD	11700	Manual	
679606.684	3082692.383	G-37SD	10300	Manual	
679681.465	3082807.799	G-38SD	5620	Manual	
679756.109	3082922.939	G-39SD	2060	Manual	
679832.158	3083041.871	G-40SD	953	Manual	
679906.421	3083156.754	G-41SD	2860	Manual	
679982.277	3083273.065	G-42SD	1080	Manual	
680056.981	3083387.33	G-43SD	13400	Manual	
680132.65	3083505.456	G-44SD	1790	Manual	
679597.188	3082450.923	G-45SD	4290	Manual	
679671.317	3082565.925	G-46SD	23100	Manual	
679745.982	3082681.386	G-47SD	10400	Manual	
679822.074	3082799.575	G-48SD	10900	Manual	
679896.612	3082915.666	G-49SD	2330	Manual	
679971.215	3083030.792	G-50SD	1180	Manual	
680046.783	3083146.999	G-51SD	2060	Manual	
680123.432	3083263.001	G-52SD	1900	Manual	
680198.058	3083379.815	G-53SD	5000	Manual	
680185.412	3083138.847	G-54SD	2870	Manual	
680260.421	3083254.807	G-55SD	12300	Manual	
680335.97	3083372.02	G-56SD	2750	Manual	
680022.008	3083237.472	J-44SD	1205	Manual	
680047.095	3083215.942	J-45SD	1960	Manual	
679887.433	3082812.936	J-46SD	5590	Manual	
679521.779	3082672.022	J-54SD	18900	Manual	
679590.092	3082773.184	J-55SD	4655	Manual	
679763.399	3083050.055	J-56SD	2180	Manual	
680108.013	3083101.352	J-57SD	14500	Manual	
680413.831	3083297.013	J-58SD	2240	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679530.943	3082575.448	G-36SD	7	Manual	
679606.684	3082692.383	G-37SD	2.9	Manual	
679671.317	3082565.925	G-46SD	1.35	Manual	
679745.982	3082681.386	G-47SD	1.35	Manual	
679521.779	3082672.022	J-54SD	1.35	Manual	
680108.013	3083101.352	J-57SD	10.6	Manual	
680413.831	3083297.013	J-58SD	1.35	Manual	

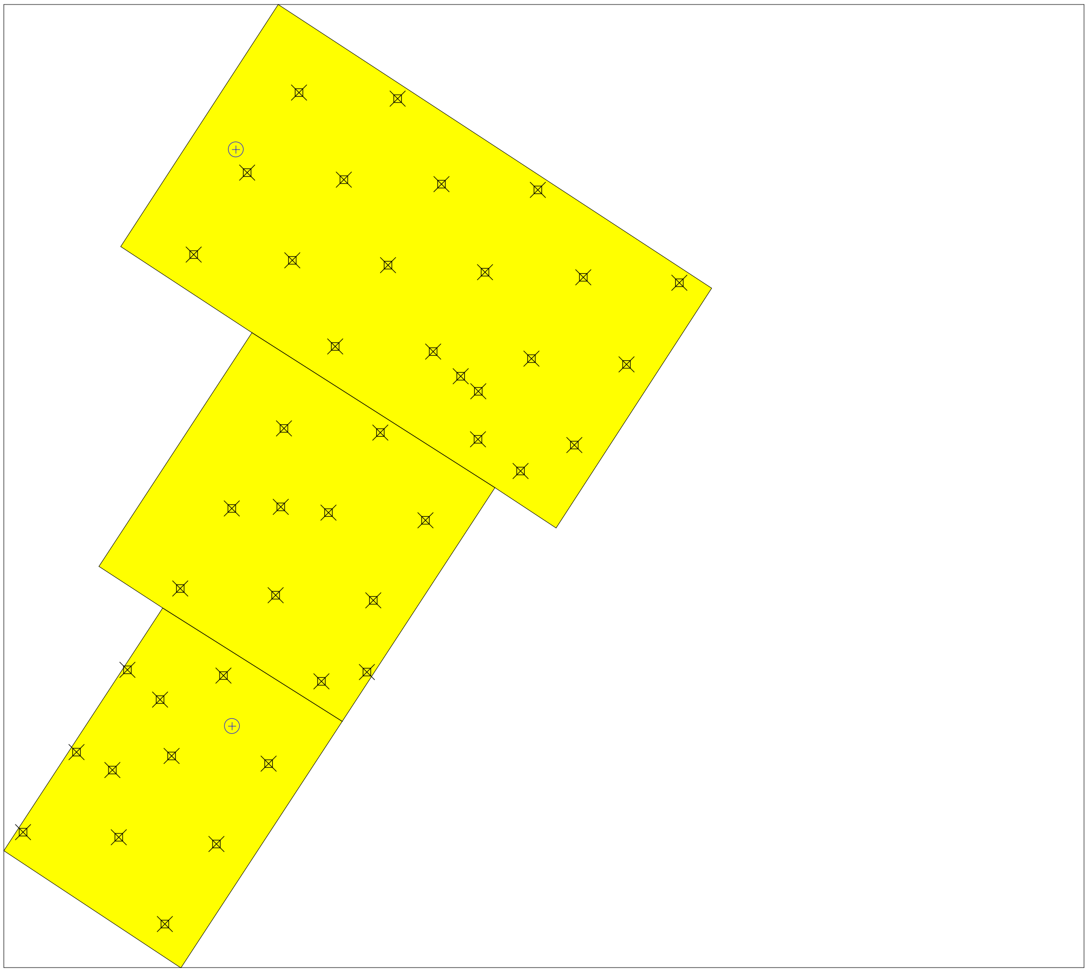
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	21
Number of samples on map [a]	45
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$11,500.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
679638.4660	3083412.5610	G-21SD	0.33	Manual	T
679715.3150	3083530.0190	G-22SD	17.3	Manual	T
679789.8310	3083644.9360	G-23SD	6.3	Manual	T
679780.1110	3083404.0250	G-24SD	1.4	Manual	T
679854.2250	3083519.8220	G-25SD	2.4	Manual	T
679931.3970	3083636.4060	G-26SD	2.13	Manual	T
679841.7740	3083280.2350	G-33SD	2.8	Manual	T
679917.7660	3083397.4160	G-34SD	0.86	Manual	T
679994.2070	3083513.4470	G-35SD	1.4	Manual	T
679982.2770	3083273.0650	G-42SD	0.43	Manual	T
680056.9810	3083387.3300	G-43SD	6.3	Manual	T
680132.6500	3083505.4560	G-44SD	1.7	Manual	T
680046.7830	3083146.9990	G-51SD	0.625	Manual	T
680123.4320	3083263.0010	G-52SD	0.75	Manual	T
680198.0580	3083379.8150	G-53SD	1.5	Manual	T
680185.4120	3083138.8470	G-54SD	2.8	Manual	T

680260.4210	3083254.8070	G-55SD	4.8	Manual	T
680335.9700	3083372.0200	G-56SD	1.4	Manual	T
680022.0080	3083237.4720	J-44SD	0.455	Manual	T
680047.0950	3083215.9420	J-45SD	0.74	Manual	T
680108.0130	3083101.3520	J-57SD	6.5	Manual	T
679699.2972	3083563.1712	G-30SD	1.6	Random	

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679619.1240	3082932.8980	G-30SD	1.6	Manual	T
679693.4050	3083047.5490	G-31SD	1.3	Manual	T
679768.2260	3083162.7270	G-32SD	2.2	Manual	T
679756.1090	3082922.9390	G-39SD	0.45	Manual	T
679832.1580	3083041.8710	G-40SD	0.75	Manual	T
679906.4210	3083156.7540	G-41SD	1.5	Manual	T
679822.0740	3082799.5750	G-48SD	2.3	Manual	T
679896.6120	3082915.6660	G-49SD	0.79	Manual	T
679971.2150	3083030.7920	G-50SD	0.31	Manual	T
679887.4330	3082812.9360	J-46SD	1.1	Manual	T
679763.3990	3083050.0550	J-56SD	1.5	Manual	T

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679393.4380	3082582.9470	G-27SD	1.6	Manual	T
679470.2860	3082698.0210	G-28SD	1.6	Manual	T
679543.3140	3082816.1060	G-29SD	1.7	Manual	T
679530.9430	3082575.4480	G-36SD	3.3	Manual	T
679606.6840	3082692.3830	G-37SD	4.7	Manual	T
679681.4650	3082807.7990	G-38SD	2.4	Manual	T
679597.1880	3082450.9230	G-45SD	0.67	Manual	T
679671.3170	3082565.9250	G-46SD	8.9	Manual	T
679745.9820	3082681.3860	G-47SD	2.6	Manual	T
679521.7790	3082672.0220	J-54SD	5	Manual	T
679590.0920	3082773.1840	J-55SD	1.3	Manual	T
679693.6062	3082734.8361		0	Random	

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations.

A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability (1-β) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where

n	is the number of samples,
S	is the estimated standard deviation of the measured values including analytical error,
Δ	is the width of the gray region,
α	is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β	is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$	is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is 1-α,
$Z_{1-\beta}$	is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is 1-β.

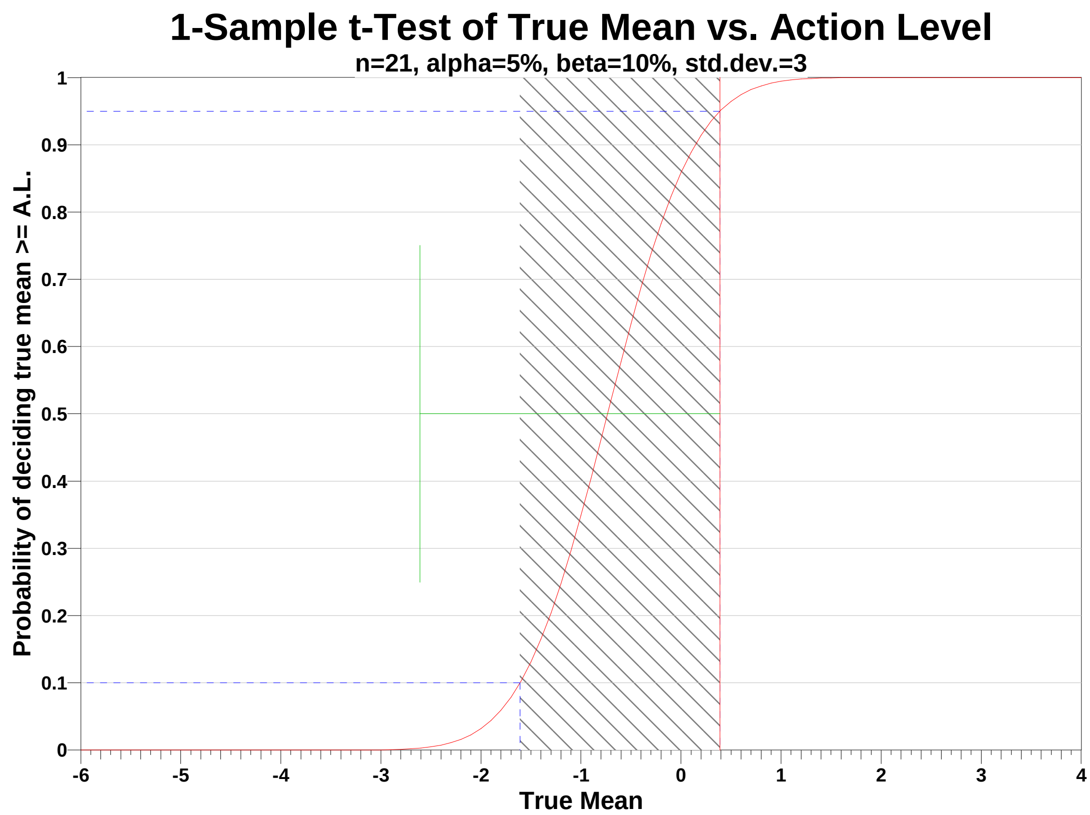
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	21	3	2	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at 1-α on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at 1-α. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions
The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis
The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=0.39		α=5		α=10		α=15	
		s=6	s=3	s=6	s=3	s=6	s=3
LBGR=90	β=5	256148	64038	202696	50675	170162	42541
	β=10	202696	50676	155492	38874	127174	31794
	β=15	170163	42542	127174	31795	101700	25426
LBGR=80	β=5	64038	16011	50675	12670	42541	10636
	β=10	50676	12670	38874	9720	31794	7949
	β=15	42542	10637	31795	7950	25426	6357
LBGR=70	β=5	28463	7117	22523	5632	18908	4728

	β=10	22523	5632	17278	4321	14131	3534
	β=15	18909	4729	14132	3534	11301	2826

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $11,500.00, which averages out to a per sample cost of $547.62. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**21 Samples**
Field collection costs		$100.00	$2,100.00
Analytical costs	$400.00	$400.00	$8,400.00
Sum of Field & Analytical costs		**$500.00**	**$10,500.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$11,500.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	0	0.31	0.33	0.43	0.45	0.455	0.625	0.67	0.74
10	0.75	0.75	0.79	0.86	1.1	1.3	1.3	1.4	1.4	1.4
20	1.5	1.5	1.5	1.6	1.6	1.6	1.6	1.7	1.7	2.13
30	2.2	2.3	2.4	2.4	2.6	2.8	2.8	3.3	4.7	4.8
40	5	6.3	6.3	6.5	8.9	17.3				

SUMMARY STATISTICS	
n	46
Min	0
Max	17.3
Range	17.3
Mean	2.4367
Median	1.55
Variance	8.768
StdDev	2.9611
Std Error	0.43659
Skewness	3.2734
Interquartile Range	1.9

Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0	0.1085	0.4	0.75	1.55	2.65	6.3	8.06	17.3

Outlier Test
Rosner's test for multiple outliers was performed to test whether the most extreme value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

In using Rosner's test to detect up to 1 outlier, a test statistic R_1 is calculated, and compared with a critical value C_1 to test the hypothesis that there is one outlier in the data.

ROSNER'S OUTLIER TEST			
k	**Test Statistic R_k**	**5% Critical Value C_k**	**Significant?**
1	4.962	3.09	Yes

The test statistic 4.962 exceeded the corresponding critical value, therefore that test is significant and we conclude that the most extreme value is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
1	17.3

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Rosner's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.8116
Shapiro-Wilk 5% Critical Value	0.944

The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the most extreme value, do not appear to follow a normal distribution at the 5% level of significance. Rosner's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

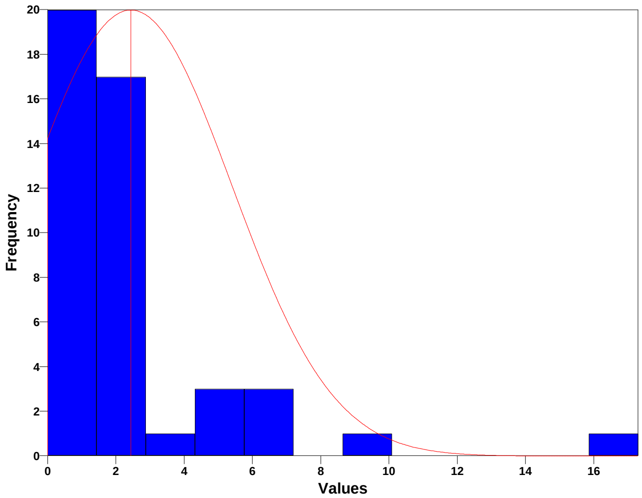
Data Plots
Graphical displays of the data are shown below.

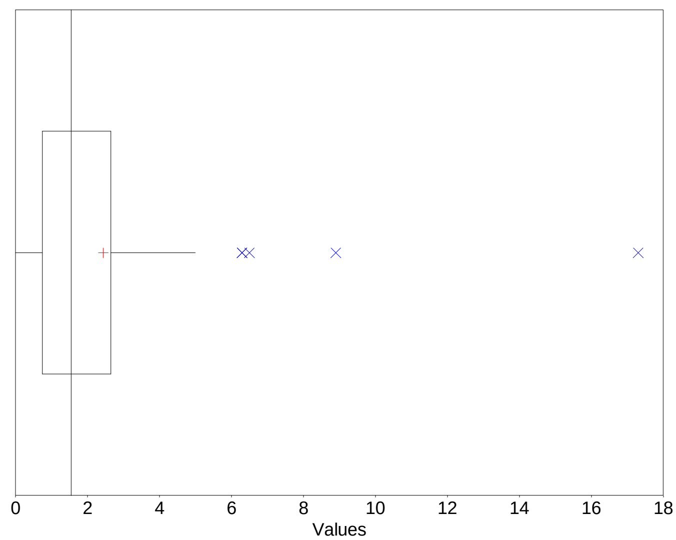
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

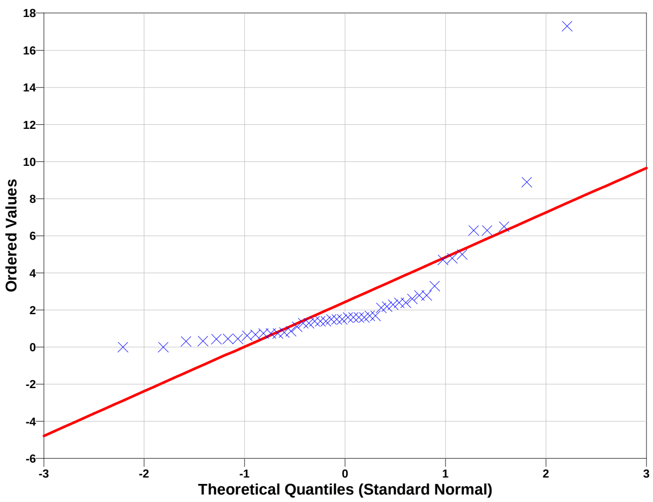
The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5

times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_n, for which a fraction p of the distribution is less than x_n. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.6649
Shapiro-Wilk 5% Critical Value	0.945

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the

data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	3.17
95% Non-Parametric (Chebyshev) UCL	4.34

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (4.34) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test

A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value t was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where

x is the sample mean of the n=46 data,

AL is the action level or threshold (0.39),

SE is the standard error = (standard deviation) / (square root of n).

This t was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=45 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
4.688	1.6794	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
4	29	Cannot Reject
Note: There may not be enough data to reject the null hypothesis (and conclude site is clean) with 95% confidence using the MARSSIM sign test.		

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Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679638.466	3083412.561	G-21SD	0.33	Manual	
679715.315	3083530.019	G-22SD	17.3	Manual	
679789.831	3083644.936	G-23SD	6.3	Manual	
679780.111	3083404.025	G-24SD	1.4	Manual	
679854.225	3083519.822	G-25SD	2.4	Manual	
679931.397	3083636.406	G-26SD	2.13	Manual	
679393.438	3082582.947	G-27SD	1.6	Manual	
679470.286	3082698.021	G-28SD	1.6	Manual	
679543.314	3082816.106	G-29SD	1.7	Manual	
679619.124	3082932.898	G-30SD	1.6	Manual	
679693.405	3083047.549	G-31SD	1.3	Manual	
679768.226	3083162.727	G-32SD	2.2	Manual	
679841.774	3083280.235	G-33SD	2.8	Manual	
679917.766	3083397.416	G-34SD	0.86	Manual	
679994.207	3083513.447	G-35SD	1.4	Manual	
679530.943	3082575.448	G-36SD	3.3	Manual	
679606.684	3082692.383	G-37SD	4.7	Manual	
679681.465	3082807.799	G-38SD	2.4	Manual	
679756.109	3082922.939	G-39SD	0.45	Manual	
679832.158	3083041.871	G-40SD	0.75	Manual	
679906.421	3083156.754	G-41SD	1.5	Manual	
679982.277	3083273.065	G-42SD	0.43	Manual	
680056.981	3083387.33	G-43SD	6.3	Manual	
680132.65	3083505.456	G-44SD	1.7	Manual	
679597.188	3082450.923	G-45SD	0.67	Manual	
679671.317	3082565.925	G-46SD	8.9	Manual	
679745.982	3082681.386	G-47SD	2.6	Manual	
679822.074	3082799.575	G-48SD	2.3	Manual	
679896.612	3082915.666	G-49SD	0.79	Manual	
679971.215	3083030.792	G-50SD	0.31	Manual	
680046.783	3083146.999	G-51SD	0.625	Manual	
680123.432	3083263.001	G-52SD	0.75	Manual	
680198.058	3083379.815	G-53SD	1.5	Manual	
680185.412	3083138.847	G-54SD	2.8	Manual	
680260.421	3083254.807	G-55SD	4.8	Manual	
680335.97	3083372.02	G-56SD	1.4	Manual	
680022.008	3083237.472	J-44SD	0.455	Manual	
680047.095	3083215.942	J-45SD	0.74	Manual	
679887.433	3082812.936	J-46SD	1.1	Manual	
679521.779	3082672.022	J-54SD	5	Manual	
679590.092	3082773.184	J-55SD	1.3	Manual	
679763.399	3083050.055	J-56SD	1.5	Manual	
680108.013	3083101.352	J-57SD	6.5	Manual	
680413.831	3083297.013	J-58SD	0.86	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	1.3	Manual	
679994.969	3082983.51	J-48S	1.2	Manual	
680057.658	3083072.075	J-49S	0.69	Manual	
680077.354	3083115.533	J-50S	0.52	Manual	
679827.115	3082729.746	J-51S	0.63	Manual	
680141.873	3083080.88	J-52S	1.1	Manual	
680170.56	3083064.674	J-53S	2.4	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	1.1	Manual	
679994.969	3082983.51	J-48S	0.965	Manual	
680057.658	3083072.075	J-49S	1	Manual	
680077.354	3083115.533	J-50S	0.72	Manual	
679827.115	3082729.746	J-51S	0.96	Manual	
680141.873	3083080.88	J-52S	1	Manual	
680170.56	3083064.674	J-53S	2.5	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	0.086	Manual	
679994.969	3082983.51	J-48S	0.087	Manual	
680057.658	3083072.075	J-49S	0.084	Manual	
680077.354	3083115.533	J-50S	0.088	Manual	
679827.115	3082729.746	J-51S	0.108	Manual	
680141.873	3083080.88	J-52S	0.1	Manual	
680170.56	3083064.674	J-53S	0.086	Manual	

Random sampling locations for comparing a mean with a fixed threshold (parametric)

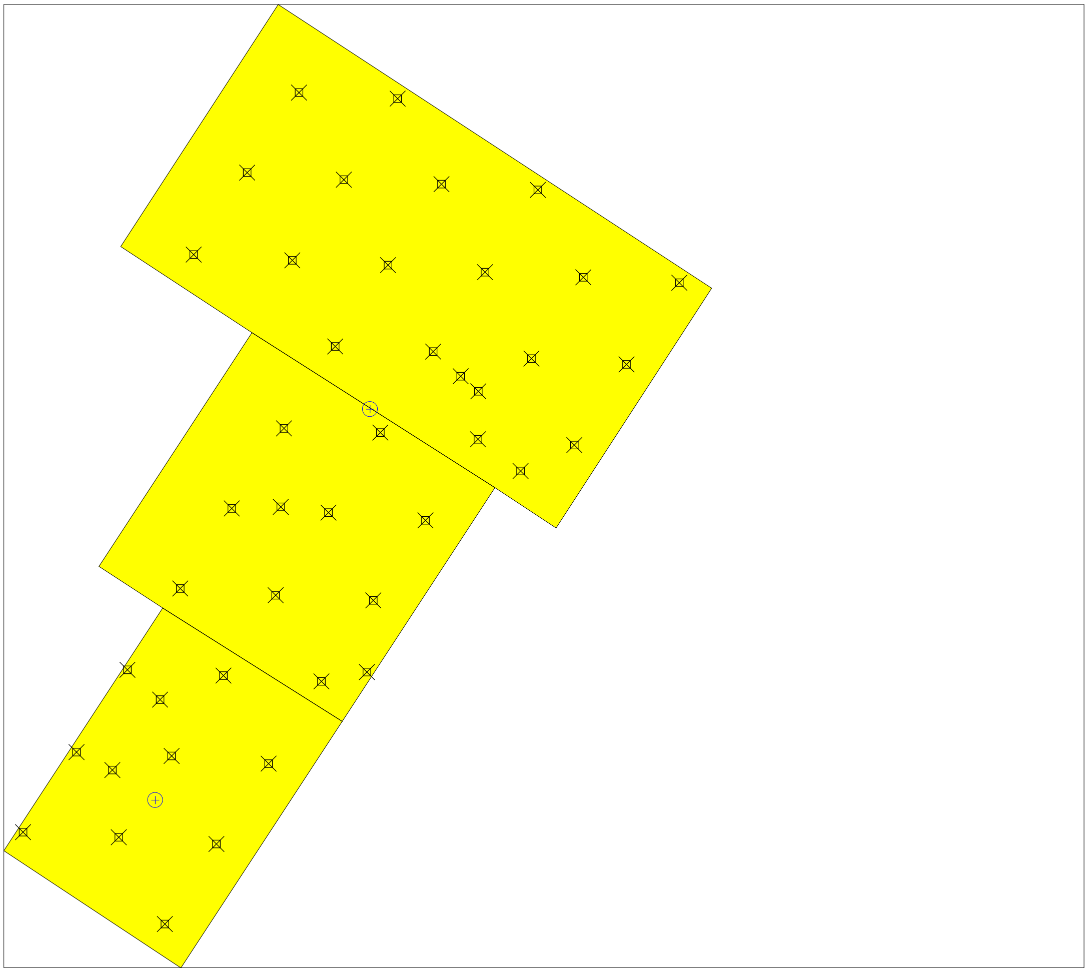
Summary

This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	21
Number of samples on map [a]	45
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$11,500.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
679638.4660	3083412.5610	G-21SD	0.153	Manual	T
679715.3150	3083530.0190	G-22SD	0.215	Manual	T
679789.8310	3083644.9360	G-23SD	0.075	Manual	T
679780.1110	3083404.0250	G-24SD	0.05	Manual	T
679854.2250	3083519.8220	G-25SD	0.06	Manual	T
679931.3970	3083636.4060	G-26SD	0.0525	Manual	T
679841.7740	3083280.2350	G-33SD	0.055	Manual	T
679917.7660	3083397.4160	G-34SD	0.0495	Manual	T
679994.2070	3083513.4470	G-35SD	0.05	Manual	T
679982.2770	3083273.0650	G-42SD	0.046	Manual	T
680056.9810	3083387.3300	G-43SD	0.729	Manual	T
680132.6500	3083505.4560	G-44SD	0.055	Manual	T
680046.7830	3083146.9990	G-51SD	0.068	Manual	T
680123.4320	3083263.0010	G-52SD	0.047	Manual	T
680198.0580	3083379.8150	G-53SD	0.055	Manual	T
680185.4120	3083138.8470	G-54SD	0.055	Manual	T

680260.4210	3083254.8070	G-55SD	0.085	Manual	T
680335.9700	3083372.0200	G-56SD	0.0495	Manual	T
680022.0080	3083237.4720	J-44SD	0.04825	Manual	T
680047.0950	3083215.9420	J-45SD	0.049	Manual	T
680108.0130	3083101.3520	J-57SD	0.065	Manual	T

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679619.1240	3082932.8980	G-30SD	0.0485	Manual	T
679693.4050	3083047.5490	G-31SD	0.048	Manual	T
679768.2260	3083162.7270	G-32SD	0.055	Manual	T
679756.1090	3082922.9390	G-39SD	0.055	Manual	T
679832.1580	3083041.8710	G-40SD	0.0485	Manual	T
679906.4210	3083156.7540	G-41SD	0.06	Manual	T
679822.0740	3082799.5750	G-48SD	0.065	Manual	T
679896.6120	3082915.6660	G-49SD	0.04725	Manual	T
679971.2150	3083030.7920	G-50SD	0.0465	Manual	T
679887.4330	3082812.9360	J-46SD	0.05	Manual	T
679763.3990	3083050.0550	J-56SD	0.05	Manual	T
679891.8976	3083190.4325	G-27SD	0.0485	Random	

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679393.4380	3082582.9470	G-27SD	0.0485	Manual	T
679470.2860	3082698.0210	G-28SD	0.04975	Manual	T
679543.3140	3082816.1060	G-29SD	0.444	Manual	T
679530.9430	3082575.4480	G-36SD	0.065	Manual	T
679606.6840	3082692.3830	G-37SD	0.095	Manual	T
679681.4650	3082807.7990	G-38SD	0.055	Manual	T
679597.1880	3082450.9230	G-45SD	0.408	Manual	T
679671.3170	3082565.9250	G-46SD	0.342	Manual	T
679745.9820	3082681.3860	G-47SD	0.065	Manual	T
679521.7790	3082672.0220	J-54SD	0.1	Manual	T
679590.0920	3082773.1840	J-55SD	0.055	Manual	T
679583.0667	3082628.6712		0	Random	

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations.

A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

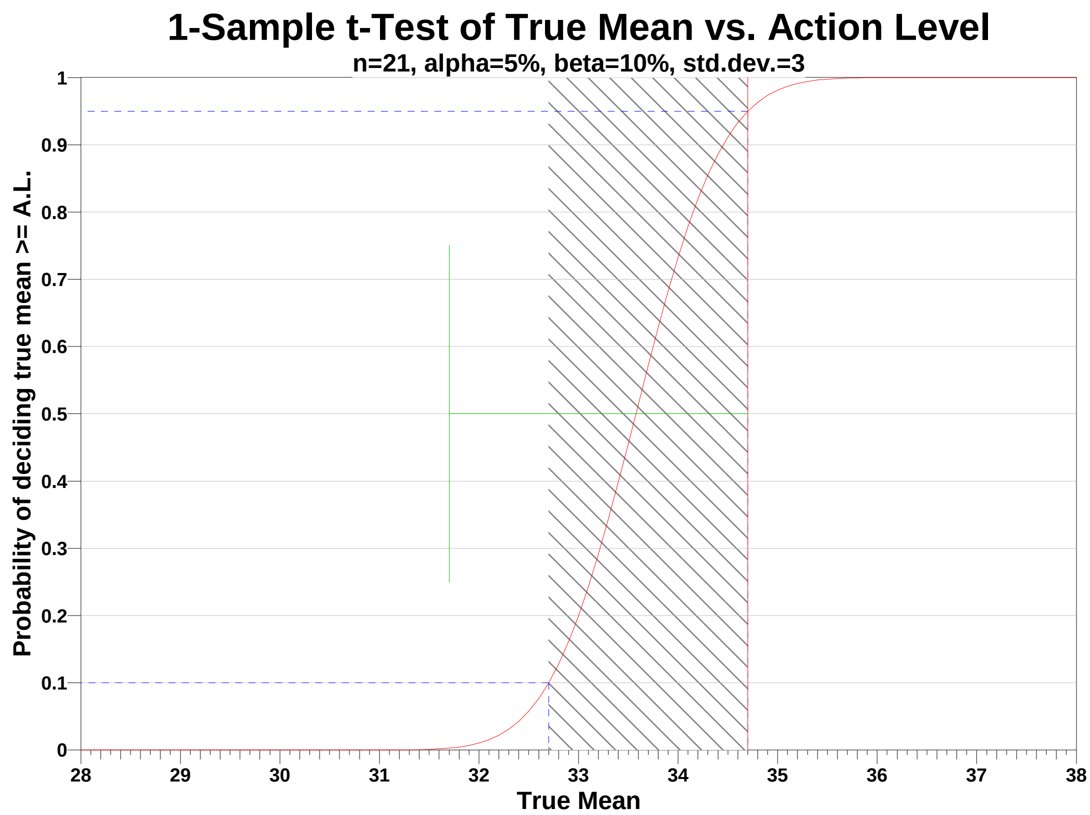
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	21	3	2	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples								
AL=34.7		α=5		α=10		α=15		
		s=6	s=3	s=6	s=3	s=6	s=3
LBGR=90	β=5	34	10	27	8	23	6
	β=10	27	8	21	6	17	5
	β=15	23	7	17	5	14	4
LBGR=80	β=5	10	4	8	3	6	2
	β=10	8	3	6	3	5	2
	β=15	7	3	5	2	4	2
LBGR=70	β=5	5	3	4	2	3	2

	β=10	5	3	4	2	3	1
	β=15	4	2	3	2	2	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $11,500.00, which averages out to a per sample cost of $547.62. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**21 Samples**
Field collection costs		$100.00	$2,100.00
Analytical costs	$400.00	$400.00	$8,400.00
Sum of Field & Analytical costs		**$500.00**	**$10,500.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$11,500.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	0	0.046	0.0465	0.047	0.04725	0.048	0.04825	0.0485	0.0485
10	0.0485	0.0485	0.049	0.0495	0.0495	0.04975	0.05	0.05	0.05	0.05
20	0.0525	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.055	0.06
30	0.06	0.065	0.065	0.065	0.065	0.068	0.075	0.085	0.095	0.1
40	0.153	0.215	0.342	0.408	0.444	0.729				

SUMMARY STATISTICS	
n	46
Min	0
Max	0.729
Range	0.729
Mean	0.096984
Median	0.055
Variance	0.017313
StdDev	0.13158
Std Error	0.0194
Skewness	3.4272
Interquartile Range	0.01725

Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0	0.0161	0.04685	0.0485	0.055	0.06575	0.2531	0.4314	0.729

Outlier Test
Rosner's test for multiple outliers was performed to test whether the most extreme value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

In using Rosner's test to detect up to 1 outlier, a test statistic R_1 is calculated, and compared with a critical value C_1 to test the hypothesis that there is one outlier in the data.

ROSNER'S OUTLIER TEST			
k	**Test Statistic R_k**	**5% Critical Value C_k**	**Significant?**
1	4.749	3.09	Yes

The test statistic 4.749 exceeded the corresponding critical value, therefore that test is significant and we conclude that the most extreme value is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
1	0.729

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Rosner's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.521
Shapiro-Wilk 5% Critical Value	0.944

The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the most extreme value, do not appear to follow a normal distribution at the 5% level of significance. Rosner's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

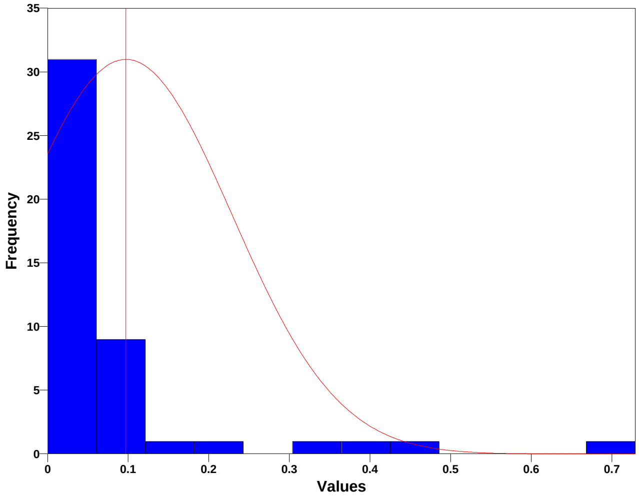
Data Plots
Graphical displays of the data are shown below.

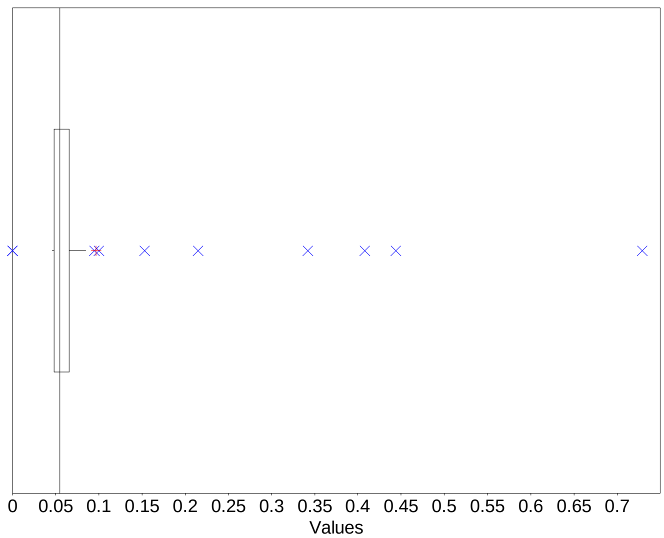
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

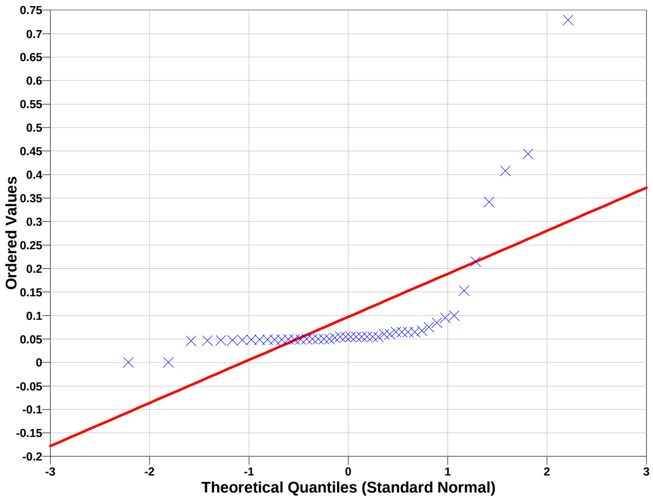
The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25^{th} and 75^{th} percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5

times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.4953
Shapiro-Wilk 5% Critical Value	0.945

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the

data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	0.1296
95% Non-Parametric (Chebyshev) UCL	0.1815

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (0.1815) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test

A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where

x is the sample mean of the n=46 data,
AL is the action level or threshold (34.7),
SE is the standard error = (standard deviation) / (square root of n).

This *t* was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=45 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-1783.7	1.6794	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
46	29	Reject

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Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679638.466	3083412.561	G-21SD	0.153	Manual	
679715.315	3083530.019	G-22SD	0.215	Manual	
679789.831	3083644.936	G-23SD	0.075	Manual	
679780.111	3083404.025	G-24SD	0.05	Manual	
679854.225	3083519.822	G-25SD	0.06	Manual	
679931.397	3083636.406	G-26SD	0.0525	Manual	
679393.438	3082582.947	G-27SD	0.0485	Manual	
679470.286	3082698.021	G-28SD	0.04975	Manual	
679543.314	3082816.106	G-29SD	0.444	Manual	
679619.124	3082932.898	G-30SD	0.0485	Manual	
679693.405	3083047.549	G-31SD	0.048	Manual	
679768.226	3083162.727	G-32SD	0.055	Manual	
679841.774	3083280.235	G-33SD	0.055	Manual	
679917.766	3083397.416	G-34SD	0.0495	Manual	
679994.207	3083513.447	G-35SD	0.05	Manual	
679530.943	3082575.448	G-36SD	0.065	Manual	
679606.684	3082692.383	G-37SD	0.095	Manual	
679681.465	3082807.799	G-38SD	0.055	Manual	
679756.109	3082922.939	G-39SD	0.055	Manual	
679832.158	3083041.871	G-40SD	0.0485	Manual	
679906.421	3083156.754	G-41SD	0.06	Manual	
679982.277	3083273.065	G-42SD	0.046	Manual	
680056.981	3083387.33	G-43SD	0.729	Manual	
680132.65	3083505.456	G-44SD	0.055	Manual	
679597.188	3082450.923	G-45SD	0.408	Manual	
679671.317	3082565.925	G-46SD	0.342	Manual	
679745.982	3082681.386	G-47SD	0.065	Manual	
679822.074	3082799.575	G-48SD	0.065	Manual	
679896.612	3082915.666	G-49SD	0.04725	Manual	
679971.215	3083030.792	G-50SD	0.0465	Manual	
680046.783	3083146.999	G-51SD	0.068	Manual	
680123.432	3083263.001	G-52SD	0.047	Manual	
680198.058	3083379.815	G-53SD	0.055	Manual	
680185.412	3083138.847	G-54SD	0.055	Manual	
680260.421	3083254.807	G-55SD	0.085	Manual	
680335.97	3083372.02	G-56SD	0.0495	Manual	
680022.008	3083237.472	J-44SD	0.04825	Manual	
680047.095	3083215.942	J-45SD	0.049	Manual	
679887.433	3082812.936	J-46SD	0.05	Manual	
679521.779	3082672.022	J-54SD	0.1	Manual	
679590.092	3082773.184	J-55SD	0.055	Manual	
679763.399	3083050.055	J-56SD	0.05	Manual	
680108.013	3083101.352	J-57SD	0.065	Manual	
680413.831	3083297.013	J-58SD	0.055	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	2.7	Manual	
679994.969	3082983.51	J-48S	3.4	Manual	
680057.658	3083072.075	J-49S	3.6	Manual	
680077.354	3083115.533	J-50S	3.2	Manual	
679827.115	3082729.746	J-51S	2.2	Manual	
680141.873	3083080.88	J-52S	4	Manual	
680170.56	3083064.674	J-53S	3.9	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	4.8	Manual	
679994.969	3082983.51	J-48S	5	Manual	
680057.658	3083072.075	J-49S	4.1	Manual	
680077.354	3083115.533	J-50S	1.4	Manual	
679827.115	3082729.746	J-51S	3.5	Manual	
680141.873	3083080.88	J-52S	3.6	Manual	
680170.56	3083064.674	J-53S	5.9	Manual	

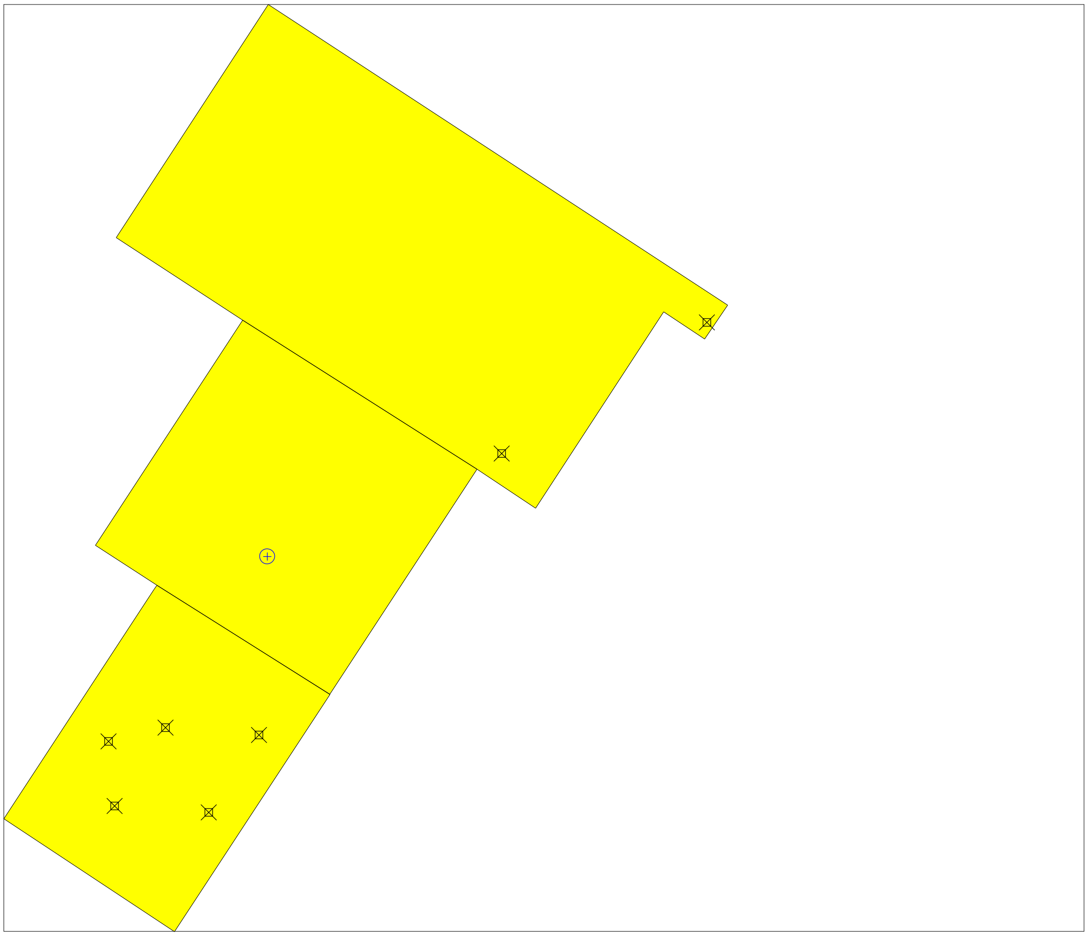
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	2
Number of samples on map [a]	8
Number of selected sample areas [b]	3
Specified sampling area [c]	606651.66 m^2
Total cost of sampling [d]	$2,000.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
680108.0130	3083101.3520	J-57SD	5.9	Manual	T
680413.8310	3083297.0130	J-58SD	5.9	Manual	T

Area: Area 2					
X Coord	Y Coord	Label	Value	Type	Historical
679758.7929	3082947.8296	G-36SD	5.9	Random	

Area: Area 3					
X Coord	Y Coord	Label	Value	Type	Historical
679530.9430	3082575.4480	G-36SD	5.9	Manual	T
679606.6840	3082692.3830	G-37SD	5.9	Manual	T
679671.3170	3082565.9250	G-46SD	5.9	Manual	T
679745.9820	3082681.3860	G-47SD	5.9	Manual	T
679521.7790	3082672.0220	J-54SD	7.7	Manual	T

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null

hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

The values of these inputs that result in the calculated number of sampling locations are:

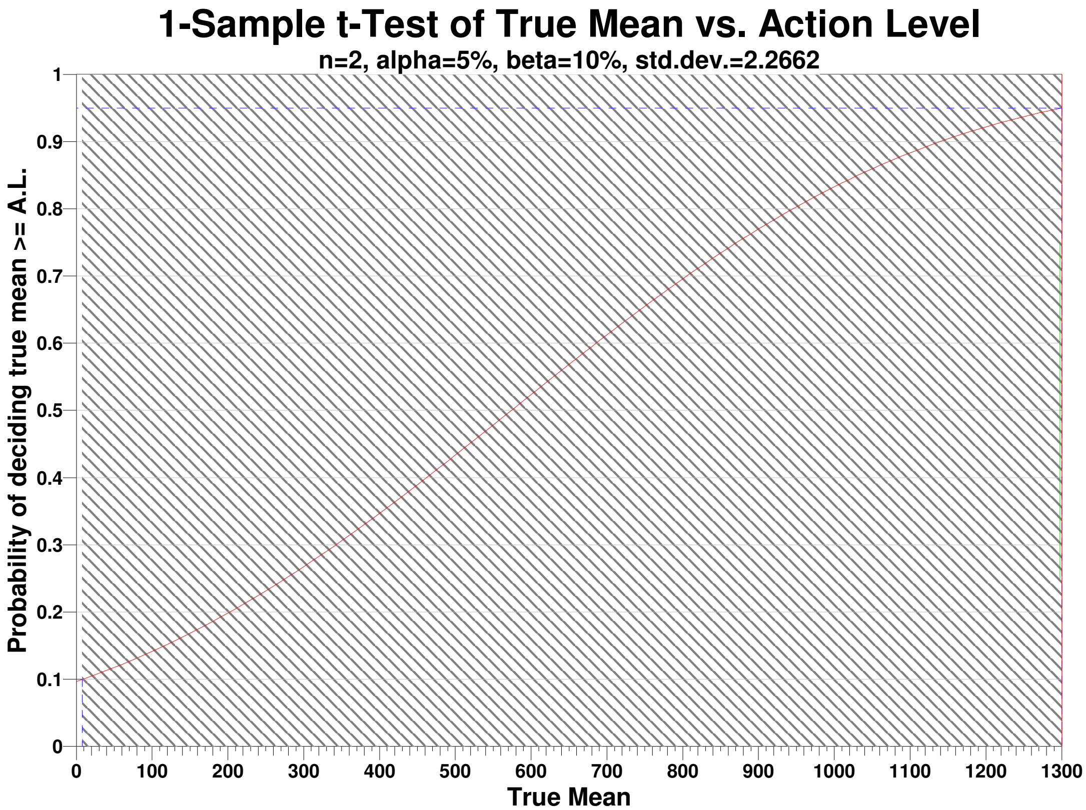
Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	2	2.2662	1292	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs

change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=1300		α=5		α=10		α=15	
		s=4.5324	s=2.2662	s=4.5324	s=2.2662	s=4.5324	s=2.2662
LBGR=90	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1
LBGR=80	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

LBGR=70	**β=5**	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $2,000.00, which averages out to a per sample cost of $1,000.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**2 Samples**
Field collection costs		$100.00	$200.00
Analytical costs	$400.00	$400.00	$800.00
Sum of Field & Analytical costs		**$500.00**	**$1,000.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$2,000.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	1	2	3	4	5	6	7	8	9	10
0	0	5.9	5.9	5.9	5.9	5.9	5.9	5.9	7.7	

SUMMARY STATISTICS								
n	9							
Min	0							
Max	7.7							
Range	7.7							
Mean	5.4444							
Median	5.9							
Variance	4.5228							
StdDev	2.1267							
Std Error	0.70889							
Skewness	-2.4937							
Interquartile Range	0							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0	0	0	5.9	5.9	5.9	7.7	7.7	7.7

Outlier Test
Dixon's extreme value test was performed to test whether the lowest value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

DIXON'S OUTLIER TEST	
Dixon Test Statistic	1
Dixon 5% Critical Value	0.554

The calculated test statistic exceeds the critical value, so the test rejects the null hypothesis that there are no outliers in the data, and concludes that the minimum value 0 is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
Min	0

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Dixon's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.4533
Shapiro-Wilk 5% Critical Value	0.803

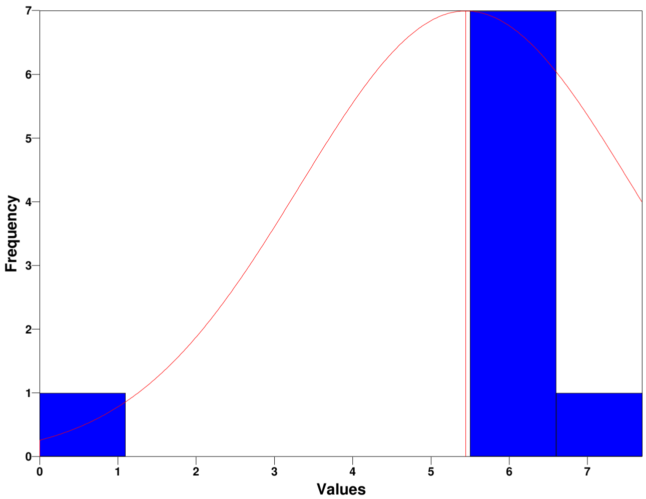
The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the minimum value 0, do not appear to follow a normal distribution at the 5% level of significance. Dixon's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

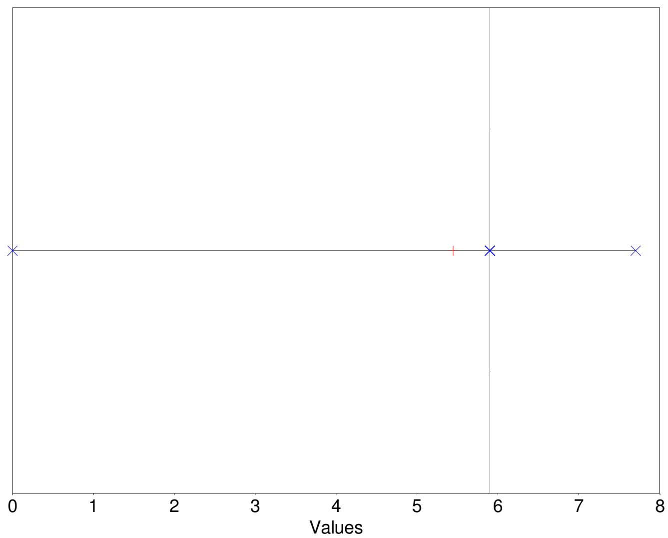
Data Plots
Graphical displays of the data are shown below.

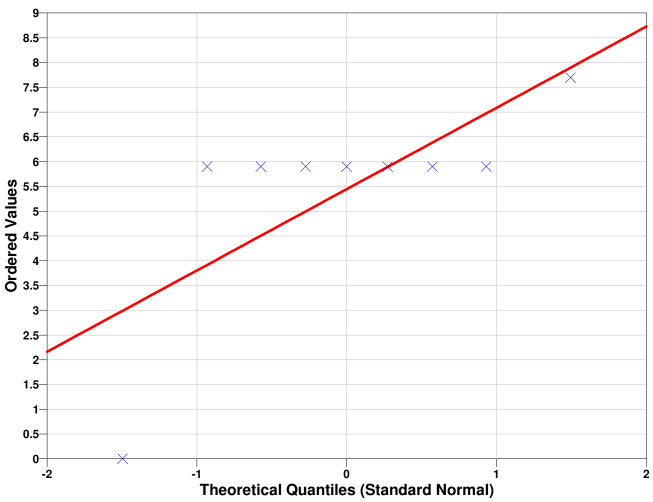
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25^{th} and 75^{th} percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.5681
Shapiro-Wilk 5% Critical Value	0.829

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN

95% Parametric UCL	6.763
95% Non-Parametric (Chebyshev) UCL	8.534

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (8.534) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=9 data,
AL is the action level or threshold (1300),
SE is the standard error = (standard deviation) / (square root of n).

This *t* was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=8 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-1826.2	1.8595	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
9	7	Reject

This report was automatically produced* by Visual Sample Plan (VSP) software version 5.000.
Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679530.943	3082575.448	G-36SD	5.9	Manual	
679606.684	3082692.383	G-37SD	5.9	Manual	
679671.317	3082565.925	G-46SD	5.9	Manual	
679745.982	3082681.386	G-47SD	5.9	Manual	
679521.779	3082672.022	J-54SD	7.7	Manual	
680108.013	3083101.352	J-57SD	5.9	Manual	
680413.831	3083297.013	J-58SD	5.9	Manual	

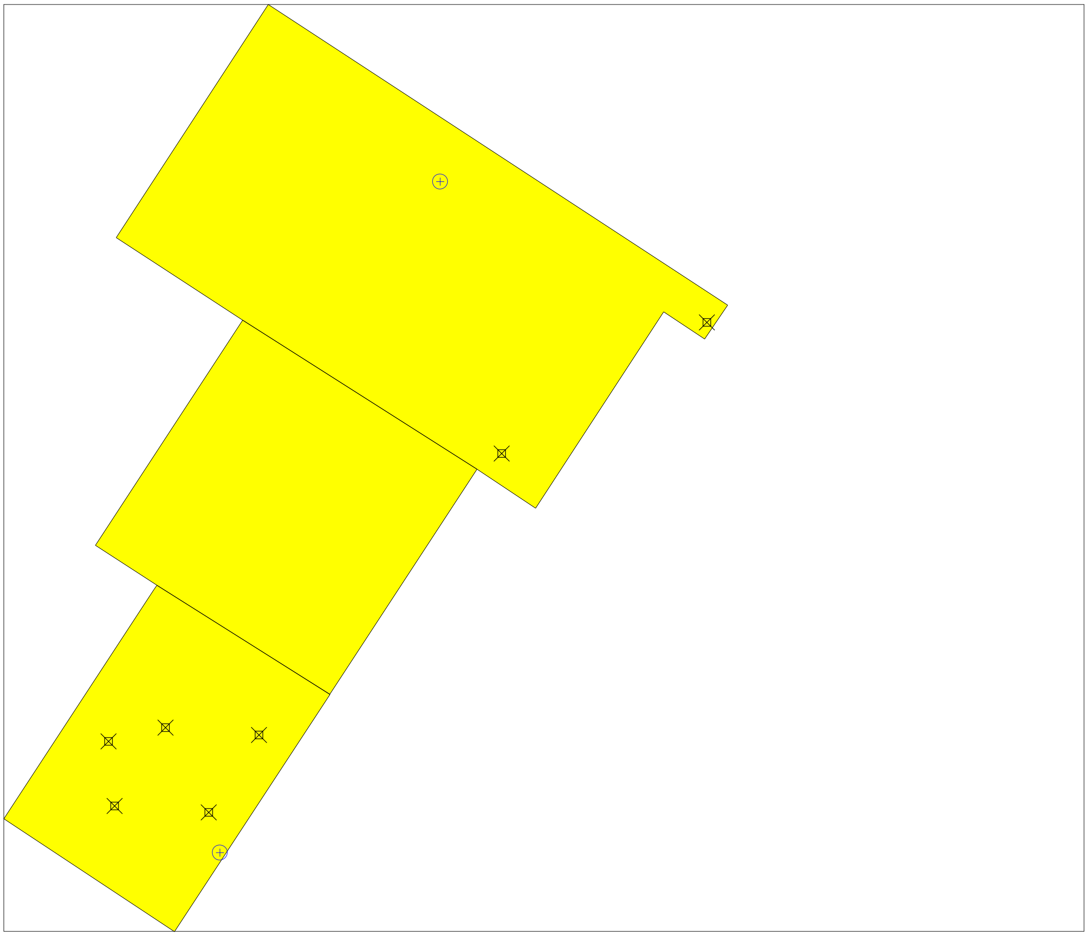
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	3
Number of samples on map [a]	9
Number of selected sample areas [b]	3
Specified sampling area [c]	606651.66 m^2
Total cost of sampling [d]	$2,500.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
680108.0130	3083101.3520	J-57SD	4.8	Manual	T
680413.8310	3083297.0130	J-58SD	10.2	Manual	T
680016.1816	3083507.3266	G-36SD	5.3	Random	

Area: Area 2					
X Coord	Y Coord	Label	Value	Type	Historical

Area: Area 3					
X Coord	Y Coord	Label	Value	Type	Historical
679530.9430	3082575.4480	G-36SD	5.3	Manual	T
679606.6840	3082692.3830	G-37SD	4	Manual	T
679671.3170	3082565.9250	G-46SD	3.2	Manual	T
679745.9820	3082681.3860	G-47SD	1.4	Manual	T
679521.7790	3082672.0220	J-54SD	1.525	Manual	T
679687.9206	3082505.6009		0	Random	

Primary Sampling Objective

The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

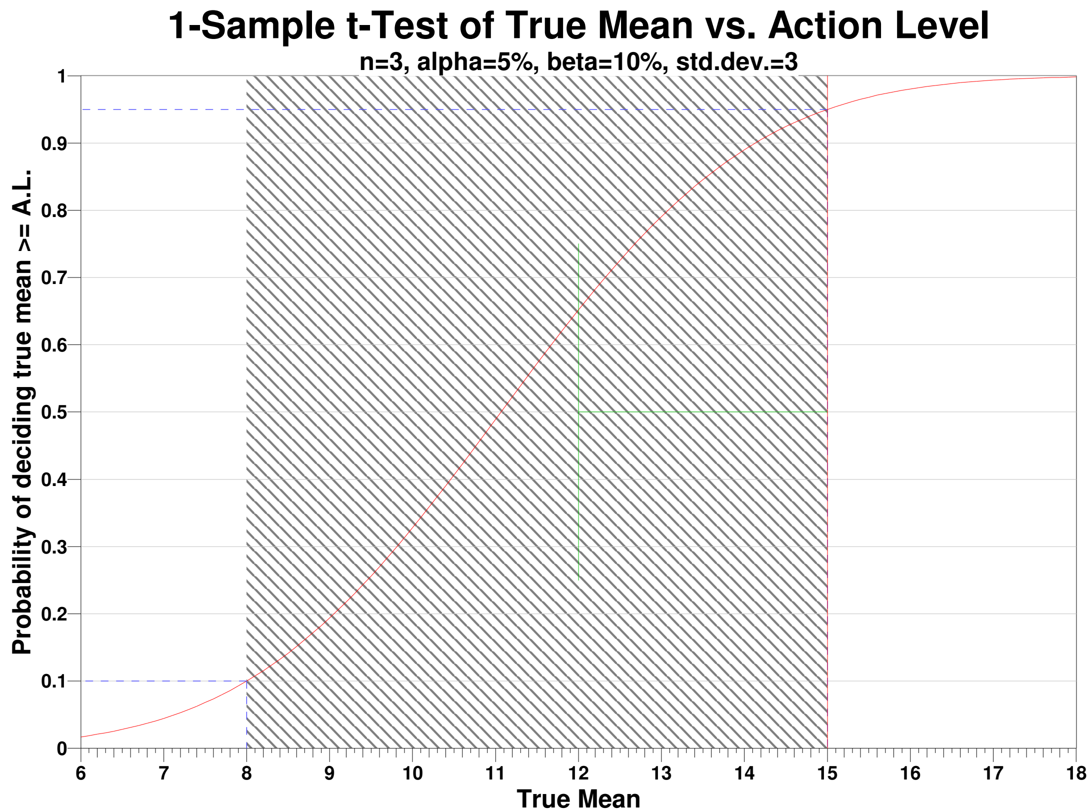
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n	Parameter					
		S	**Δ**	**α**	**β**	***Z*** $\mathbf{Z_{1-\alpha}}$ [a]	$\mathbf{Z_{1-\beta}}$ [b]
	3	3	7	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at 1-α. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=15		α=5		α=10		α=15	
		s=6	s=3	s=6	s=3	s=6	s=3
LBGR=90	β=5	175	45	138	36	116	30
	β=10	139	36	106	28	87	23
	β=15	117	31	87	23	70	18
LBGR=80	β=5	45	13	36	10	30	8
	β=10	36	10	28	8	23	6

	β=15	31	9	23	7	18	5
LBGR=70	**β=5**	21	7	17	5	14	4
	β=10	17	6	13	4	11	3
	β=15	15	5	11	4	9	3

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $2,500.00, which averages out to a per sample cost of $833.33. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**3 Samples**
Field collection costs		$100.00	$300.00
Analytical costs	$400.00	$400.00	$1,200.00
Sum of Field & Analytical costs		**$500.00**	**$1,500.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$2,500.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	1.4	1.525	3.2	4	4	4.8	5.3	5.3	10.2

SUMMARY STATISTICS	
n	10
Min	0
Max	10.2
Range	10.2
Mean	3.9725
Median	4
Variance	7.9976
StdDev	2.828
Std Error	0.89429
Skewness	0.93294
Interquartile Range	3.8062

Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**

0	0	0.14	1.494	4	5.3	9.71	10.2	10.2

Outlier Test
Dixon's extreme value test was performed to test whether the lowest value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

DIXON'S OUTLIER TEST	
Dixon Test Statistic	0.032051
Dixon 5% Critical Value	0.512

The calculated test statistic does not exceed the critical value, so the test cannot reject the null hypothesis that there are no outliers in the data, and concludes that the minimum value 0 is not an outlier at the 5% significance level.

Because Dixon's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.8653
Shapiro-Wilk 5% Critical Value	0.818

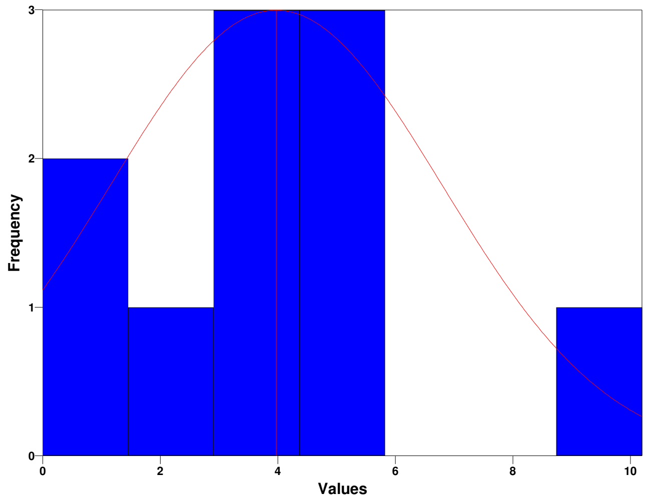
The calculated Shapiro-Wilk test statistic exceeds the 5% Shapiro-Wilk critical value, so the test cannot reject the hypothesis that the data are normal and concludes that the data, excluding the minimum value 0, do appear to follow a normal distribution at the 5% level of significance.

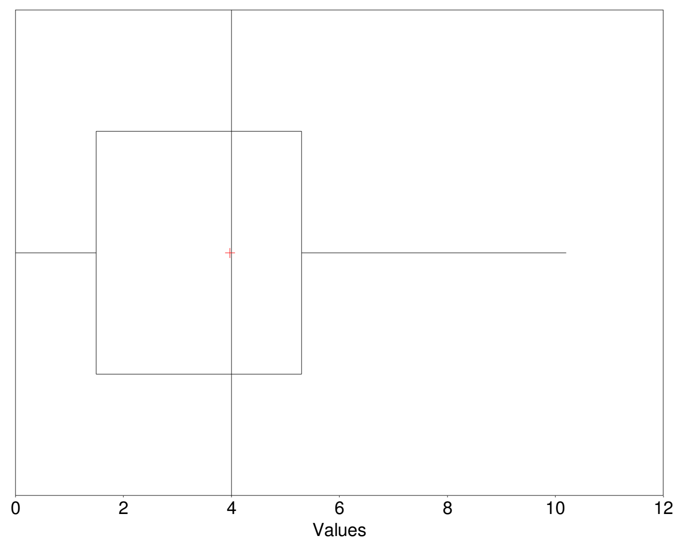
Data Plots
Graphical displays of the data are shown below.

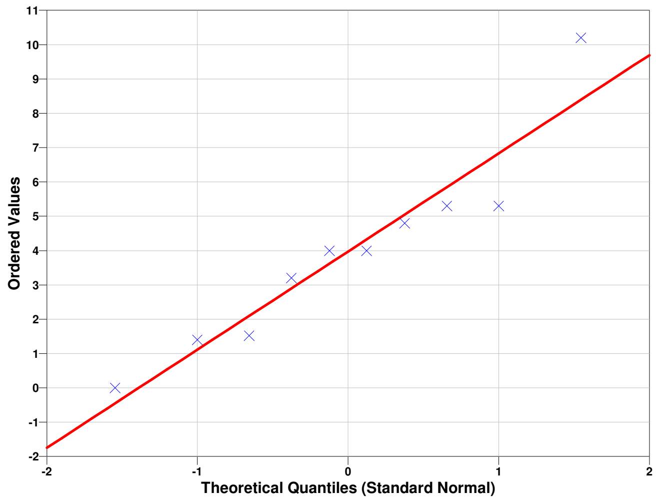
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The pth quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.9209
Shapiro-Wilk 5% Critical Value	0.842

The calculated SW test statistic exceeds the 5% Shapiro-Wilk critical value, so we cannot reject the hypothesis that the data are normal, or in other words the data appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	5.612

95% Non-Parametric (Chebyshev) UCL	7.871

Because the data appear to be normally distributed according to the goodness-of-fit test performed above, the parametric UCL (5.612) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=10 data,
AL is the action level or threshold (15),
SE is the standard error = (standard deviation) / (square root of n).

This t was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=9 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-12.331	1.8331	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

This report was automatically produced* by Visual Sample Plan (VSP) software version 5.000.
Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679530.943	3082575.448	G-36SD	5.3	Manual	
679606.684	3082692.383	G-37SD	4	Manual	
679671.317	3082565.925	G-46SD	3.2	Manual	
679745.982	3082681.386	G-47SD	1.4	Manual	
679521.779	3082672.022	J-54SD	1.525	Manual	
680108.013	3083101.352	J-57SD	4.8	Manual	
680413.831	3083297.013	J-58SD	10.2	Manual	

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679530.943	3082575.448	G-36SD	3.9	Manual	
679606.684	3082692.383	G-37SD	2.7	Manual	
679671.317	3082565.925	G-46SD	2.7	Manual	
679745.982	3082681.386	G-47SD	4.3	Manual	
679521.779	3082672.022	J-54SD	2.7	Manual	
680108.013	3083101.352	J-57SD	2.7	Manual	
680413.831	3083297.013	J-58SD	9.2	Manual	

Random sampling locations for comparing a mean with a fixed threshold (parametric)

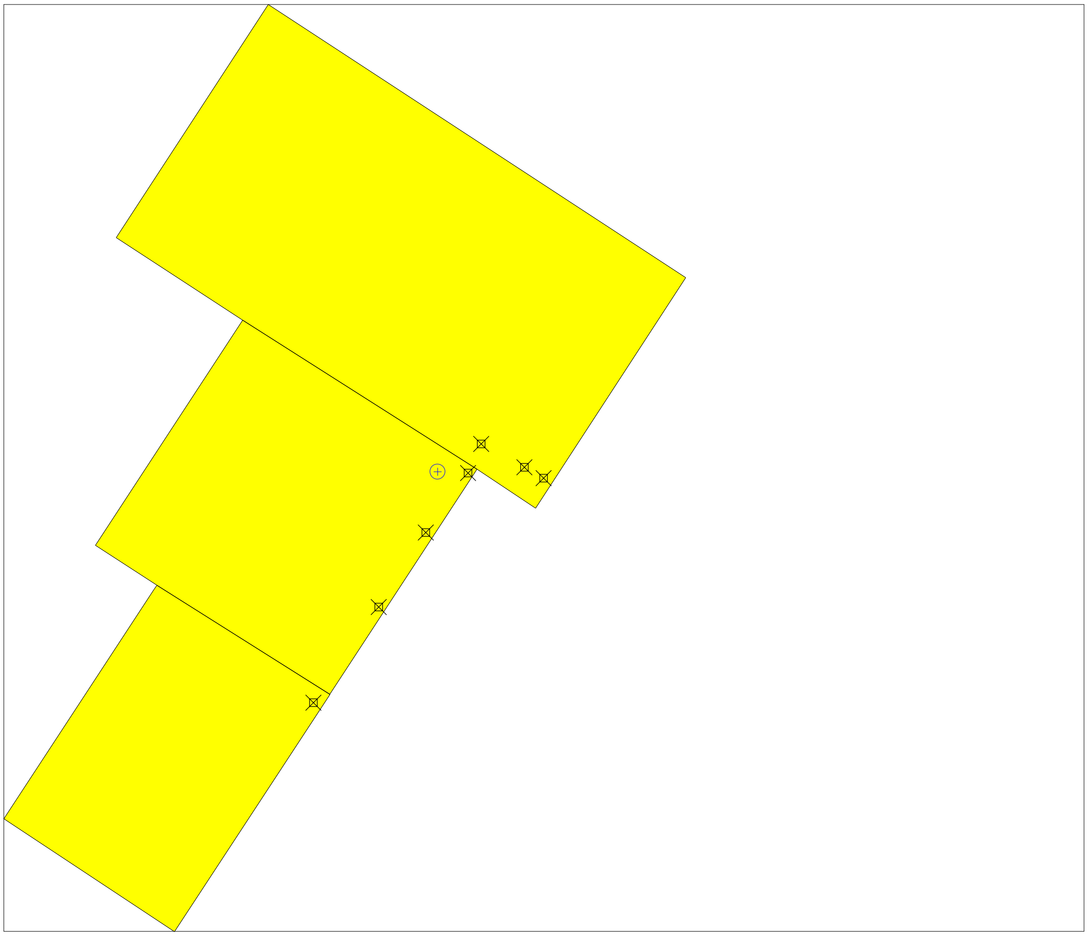
Summary

This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	2
Number of samples on map [a]	8
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$2,000.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
680077.3540	3083115.5330	J-50S	5.1	Manual	T
680141.8730	3083080.8800	J-52S	5.3	Manual	T
680170.5600	3083064.6740	J-53S	7.9	Manual	T

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679924.8150	3082872.3490	J-47S	4.4	Manual	T
679994.9690	3082983.5100	J-48S	5.5	Manual	T
680057.6580	3083072.0750	J-49S	4.5	Manual	T
680012.7245	3083074.0231	J-51S	4.6	Random	

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679827.1150	3082729.7460	J-51S	4.6	Manual	T

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null

hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

The values of these inputs that result in the calculated number of sampling locations are:

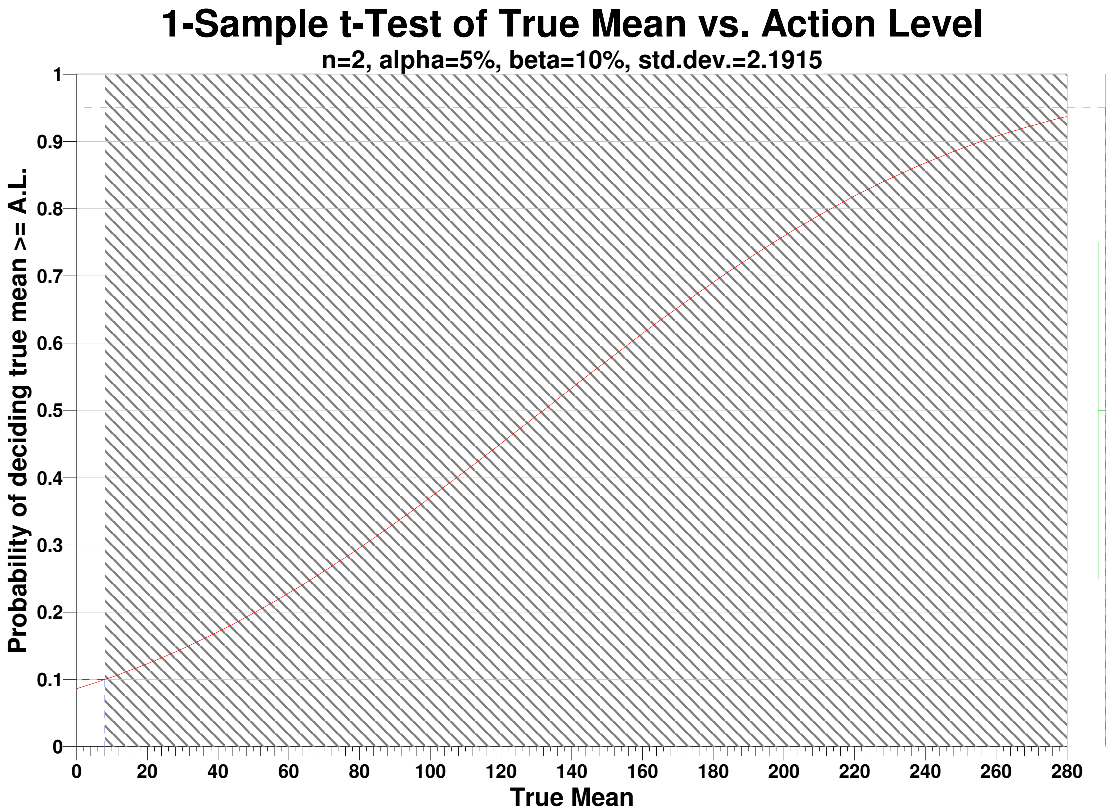
Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	2	2.1915	283	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs

change, the number of samples that result in the correct curve changes.



Statistical Assumptions
The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis
The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=291		α=5		α=10		α=15	
		s=4.383	s=2.1915	s=4.383	s=2.1915	s=4.383	s=2.1915
LBGR=90	β=5	2	2	2	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1
LBGR=80	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

LBGR=70	**β=5**	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $2,000.00, which averages out to a per sample cost of $1,000.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**2 Samples**
Field collection costs		$100.00	$200.00
Analytical costs	$400.00	$400.00	$800.00
Sum of Field & Analytical costs		**$500.00**	**$1,000.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$2,000.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	1	2	3	4	5	6	7	8	9	10
0	0	4.4	4.5	4.6	4.6	5.1	5.3	5.5	7.9	

SUMMARY STATISTICS								
n	9							
Min	0							
Max	7.9							
Range	7.9							
Mean	4.6556							
Median	4.6							
Variance	4.2028							
StdDev	2.0501							
Std Error	0.68336							
Skewness	-1.2277							
Interquartile Range	0.95							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0	0	0	4.45	4.6	5.4	7.9	7.9	7.9

Outlier Test
Dixon's extreme value test was performed to test whether the lowest value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

DIXON'S OUTLIER TEST	
Dixon Test Statistic	0.8
Dixon 5% Critical Value	0.554

The calculated test statistic exceeds the critical value, so the test rejects the null hypothesis that there are no outliers in the data, and concludes that the minimum value 0 is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
Min	0

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Dixon's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.7602
Shapiro-Wilk 5% Critical Value	0.803

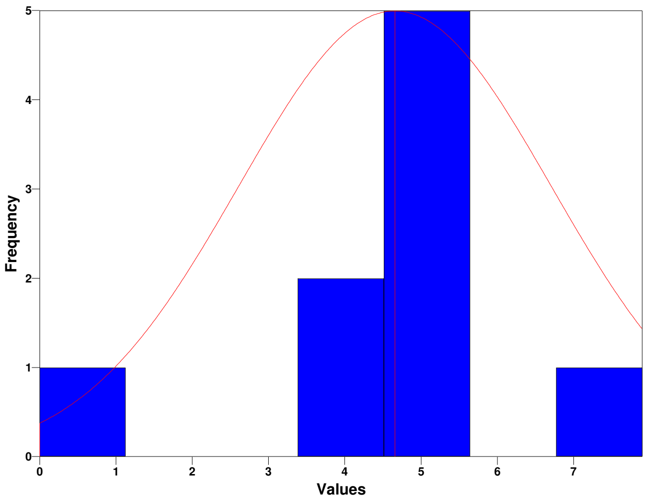
The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the minimum value 0, do not appear to follow a normal distribution at the 5% level of significance. Dixon's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

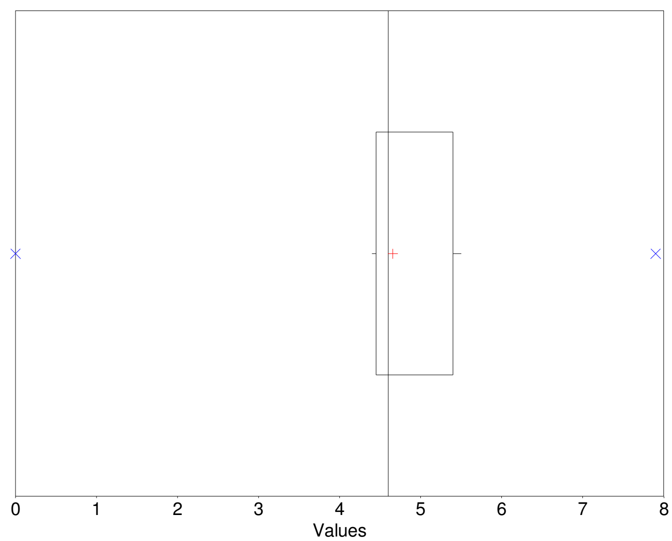
Data Plots
Graphical displays of the data are shown below.

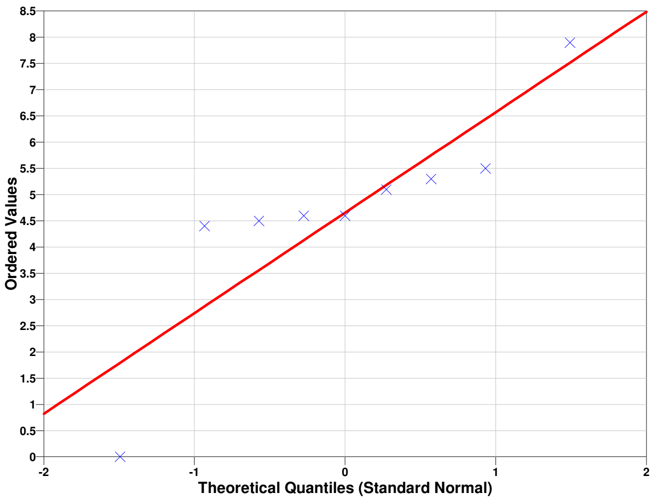
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25^{th} and 75^{th} percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests
A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.8085
Shapiro-Wilk 5% Critical Value	0.829

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean
Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN

95% Parametric UCL	5.926
95% Non-Parametric (Chebyshev) UCL	7.634

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (7.634) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=9 data,
AL is the action level or threshold (291),
SE is the standard error = (standard deviation) / (square root of n).

This *t* was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=8 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-419.03	1.8595	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
9	7	Reject

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Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	4.4	Manual	
679994.969	3082983.51	J-48S	5.5	Manual	
680057.658	3083072.075	J-49S	4.5	Manual	
680077.354	3083115.533	J-50S	5.1	Manual	
679827.115	3082729.746	J-51S	4.6	Manual	
680141.873	3083080.88	J-52S	5.3	Manual	
680170.56	3083064.674	J-53S	7.9	Manual	

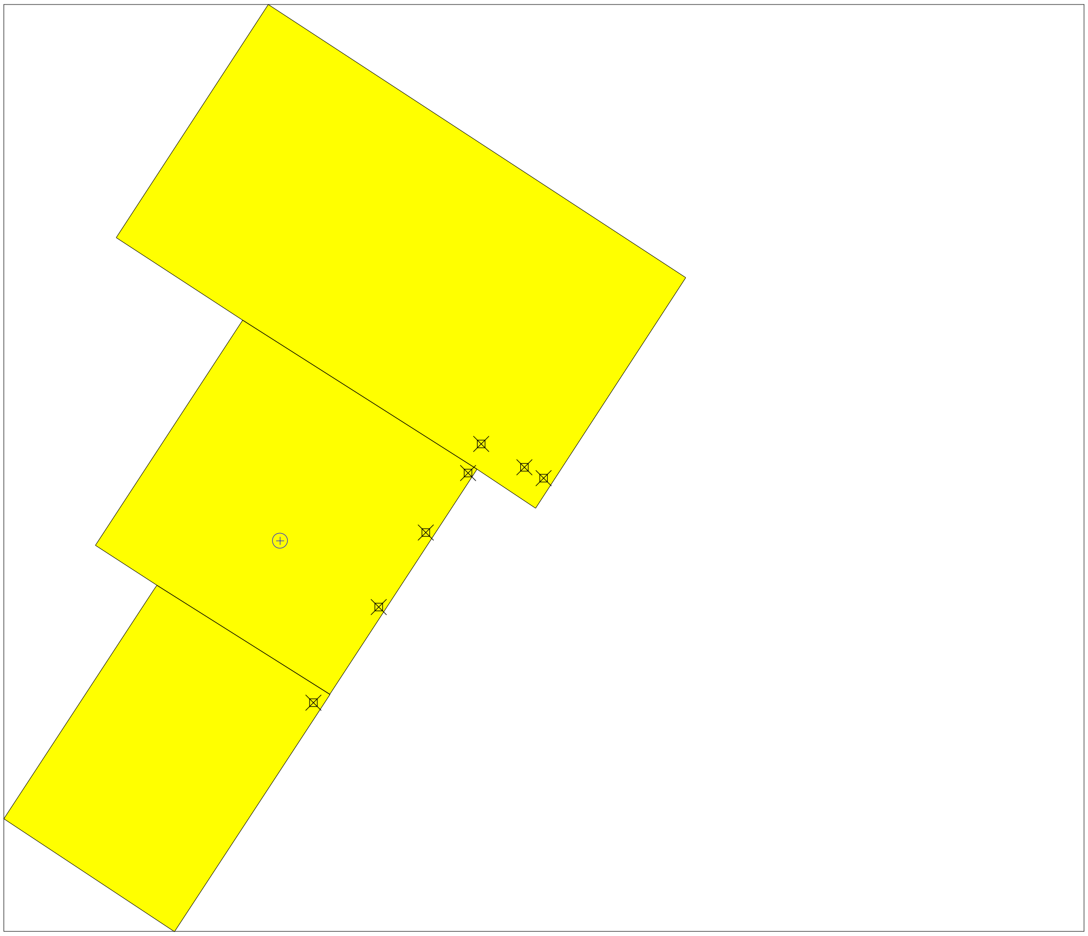
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	2
Number of samples on map [a]	8
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$2,000.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
680077.3540	3083115.5330	J-50S	1.4	Manual	T
680141.8730	3083080.8800	J-52S	3.6	Manual	T
680170.5600	3083064.6740	J-53S	5.9	Manual	T

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679924.8150	3082872.3490	J-47S	4.8	Manual	T
679994.9690	3082983.5100	J-48S	5	Manual	T
680057.6580	3083072.0750	J-49S	4.1	Manual	T
679777.7540	3082971.2341	J-51S	3.5	Random	

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679827.1150	3082729.7460	J-51S	3.5	Manual	T

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null

hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

The values of these inputs that result in the calculated number of sampling locations are:

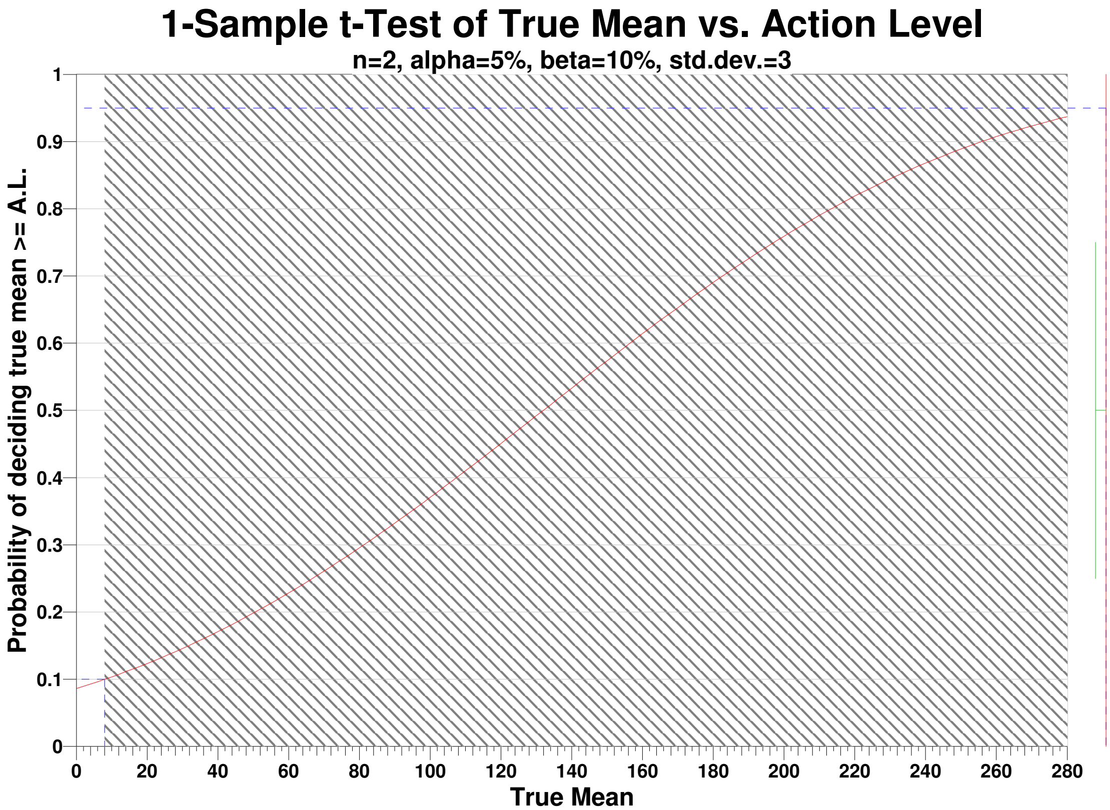
Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	2	3	283	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs

change, the number of samples that result in the correct curve changes.



Statistical Assumptions
The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis
The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=291		α=5		α=10		α=15	
		s=6	s=3	s=6	s=3	s=6	s=3
LBGR=90	β=5	2	2	2	1	1	1
	β=10	2	2	2	1	1	1
	β=15	2	2	2	1	1	1
LBGR=80	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

LBGR=70	**β=5**	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $2,000.00, which averages out to a per sample cost of $1,000.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**2 Samples**
Field collection costs		$100.00	$200.00
Analytical costs	$400.00	$400.00	$800.00
Sum of Field & Analytical costs		**$500.00**	**$1,000.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$2,000.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	1	2	3	4	5	6	7	8	9	10
0	1.4	3.5	3.5	3.6	4.1	4.8	5	5.9		

SUMMARY STATISTICS								
n	8							
Min	1.4							
Max	5.9							
Range	4.5							
Mean	3.975							
Median	3.85							
Variance	1.8107							
StdDev	1.3456							
Std Error	0.47575							
Skewness	-0.66974							
Interquartile Range	1.45							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
1.4	1.4	1.4	3.5	3.85	4.95	5.9	5.9	5.9

Outlier Test
Dixon's extreme value test was performed to test whether the lowest value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

DIXON'S OUTLIER TEST	
Dixon Test Statistic	0.58333
Dixon 5% Critical Value	0.554

The calculated test statistic exceeds the critical value, so the test rejects the null hypothesis that there are no outliers in the data, and concludes that the minimum value 1.4 is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
Min	1.4

Because Dixon's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.8807
Shapiro-Wilk 5% Critical Value	0.803

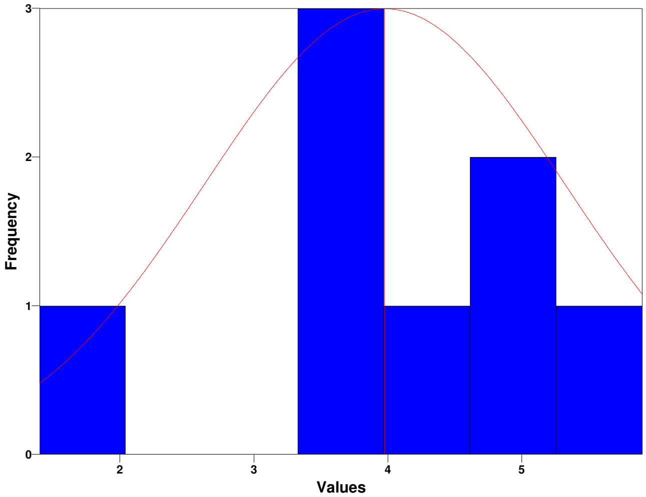
The calculated Shapiro-Wilk test statistic exceeds the 5% Shapiro-Wilk critical value, so the test cannot reject the hypothesis that the data are normal and concludes that the data, excluding the minimum value 1.4, do appear to follow a normal distribution at the 5% level of significance.

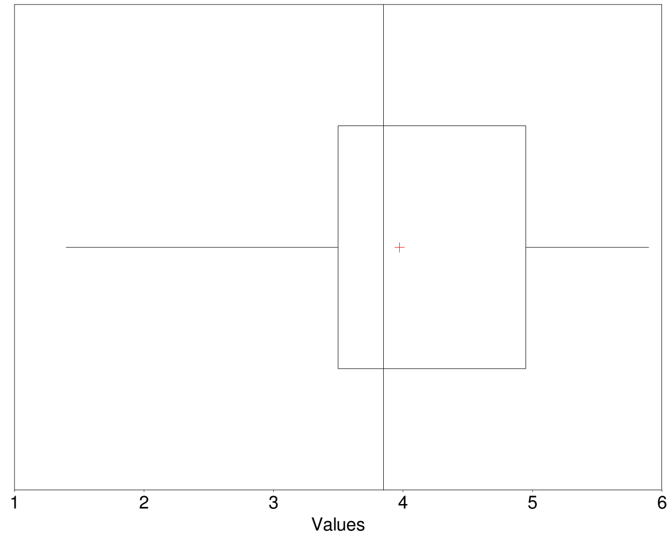
Data Plots
Graphical displays of the data are shown below.

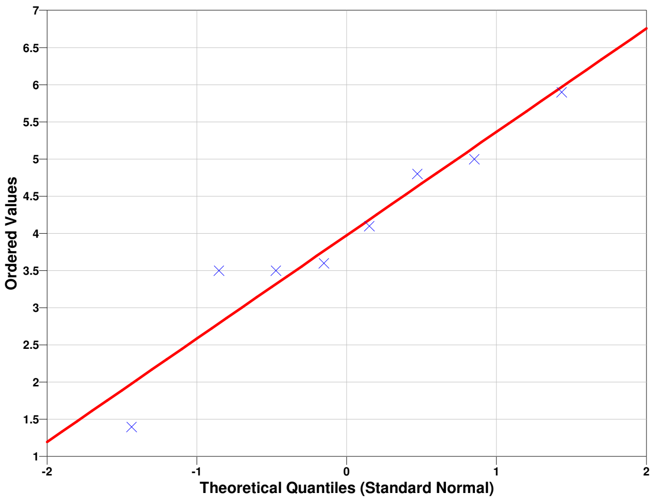
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25^{th} and 75^{th} percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests
A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.9405
Shapiro-Wilk 5% Critical Value	0.818

The calculated SW test statistic exceeds the 5% Shapiro-Wilk critical value, so we cannot reject the hypothesis that the data are normal, or in other words the data appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean
Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	4.876

95% Non-Parametric (Chebyshev) UCL	6.049

Because the data appear to be normally distributed according to the goodness-of-fit test performed above, the parametric UCL (4.876) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=8 data,
AL is the action level or threshold (291),
SE is the standard error = (standard deviation) / (square root of n).

This t was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=7 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-603.31	1.8946	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	4.8	Manual	
679994.969	3082983.51	J-48S	5	Manual	
680057.658	3083072.075	J-49S	4.1	Manual	
680077.354	3083115.533	J-50S	1.4	Manual	
679827.115	3082729.746	J-51S	3.5	Manual	
680141.873	3083080.88	J-52S	3.6	Manual	
680170.56	3083064.674	J-53S	5.9	Manual	

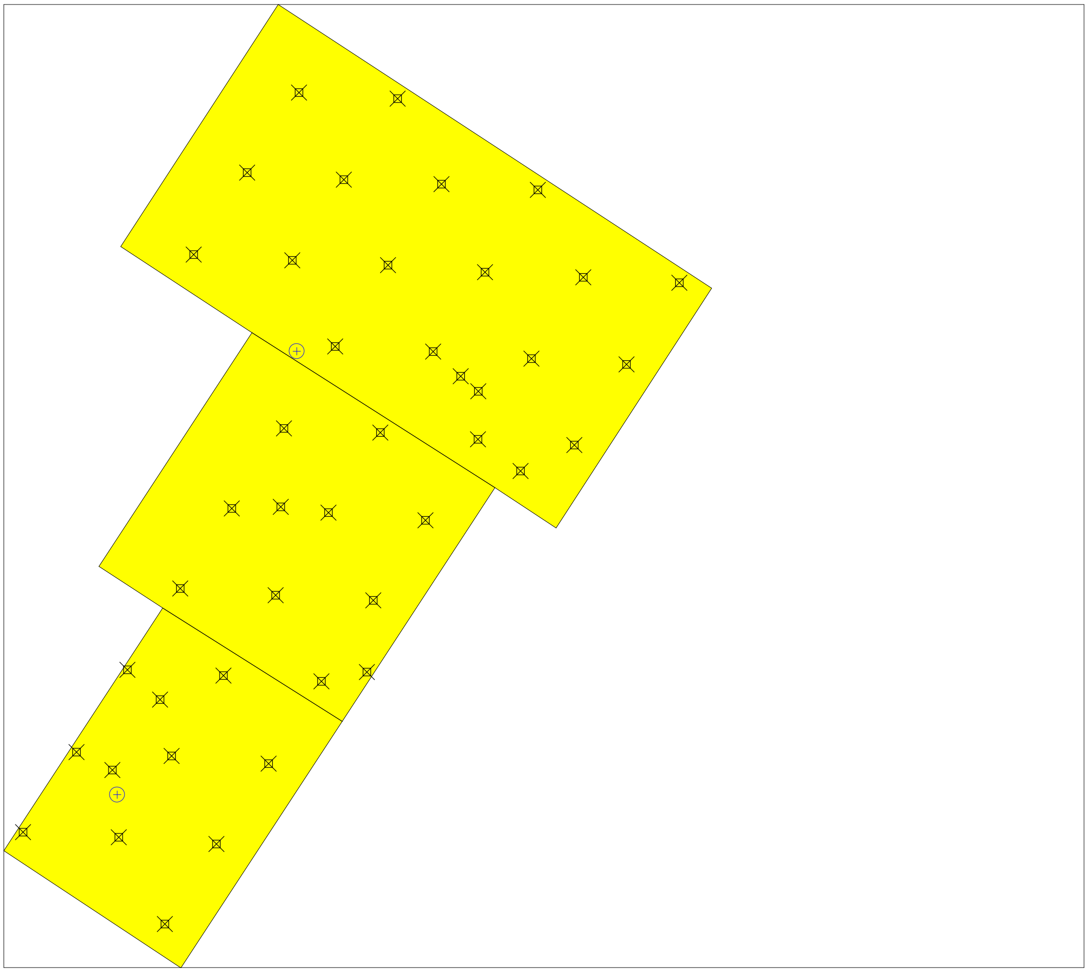
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	21
Number of samples on map [a]	45
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$11,500.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679638.4660	3083412.5610	G-21SD	134	Manual	T
679715.3150	3083530.0190	G-22SD	611	Manual	T
679789.8310	3083644.9360	G-23SD	207	Manual	T
679780.1110	3083404.0250	G-24SD	53.4	Manual	T
679854.2250	3083519.8220	G-25SD	68.2	Manual	T
679931.3970	3083636.4060	G-26SD	257.6	Manual	T
679841.7740	3083280.2350	G-33SD	91.2	Manual	T
679917.7660	3083397.4160	G-34SD	11.2	Manual	T
679994.2070	3083513.4470	G-35SD	40	Manual	T
679982.2770	3083273.0650	G-42SD	26.7	Manual	T
680056.9810	3083387.3300	G-43SD	463	Manual	T
680132.6500	3083505.4560	G-44SD	88.2	Manual	T
680046.7830	3083146.9990	G-51SD	76.1	Manual	T
680123.4320	3083263.0010	G-52SD	95.9	Manual	T
680198.0580	3083379.8150	G-53SD	104	Manual	T
680185.4120	3083138.8470	G-54SD	128	Manual	T

680260.4210	3083254.8070	G-55SD	569	Manual	T
680335.9700	3083372.0200	G-56SD	86.4	Manual	T
680022.0080	3083237.4720	J-44SD	29.4	Manual	T
680047.0950	3083215.9420	J-45SD	91.4	Manual	T
680108.0130	3083101.3520	J-57SD	802	Manual	T
679786.3895	3083273.6620	G-30SD	17.2	Random	

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679619.1240	3082932.8980	G-30SD	17.2	Manual	T
679693.4050	3083047.5490	G-31SD	16.9	Manual	T
679768.2260	3083162.7270	G-32SD	52.3	Manual	T
679756.1090	3082922.9390	G-39SD	37.8	Manual	T
679832.1580	3083041.8710	G-40SD	27.5	Manual	T
679906.4210	3083156.7540	G-41SD	37.8	Manual	T
679822.0740	3082799.5750	G-48SD	812	Manual	T
679896.6120	3082915.6660	G-49SD	24.7	Manual	T
679971.2150	3083030.7920	G-50SD	58.3	Manual	T
679887.4330	3082812.9360	J-46SD	305	Manual	T
679763.3990	3083050.0550	J-56SD	27	Manual	T

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679393.4380	3082582.9470	G-27SD	29.6	Manual	T
679470.2860	3082698.0210	G-28SD	32.25	Manual	T
679543.3140	3082816.1060	G-29SD	34.5	Manual	T
679530.9430	3082575.4480	G-36SD	119	Manual	T
679606.6840	3082692.3830	G-37SD	187	Manual	T
679681.4650	3082807.7990	G-38SD	122	Manual	T
679597.1880	3082450.9230	G-45SD	96.5	Manual	T
679671.3170	3082565.9250	G-46SD	896	Manual	T
679745.9820	3082681.3860	G-47SD	64.1	Manual	T
679521.7790	3082672.0220	J-54SD	208	Manual	T
679590.0920	3082773.1840	J-55SD	59.8	Manual	T
679528.3937	3082636.5369		0	Random	

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations.

A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

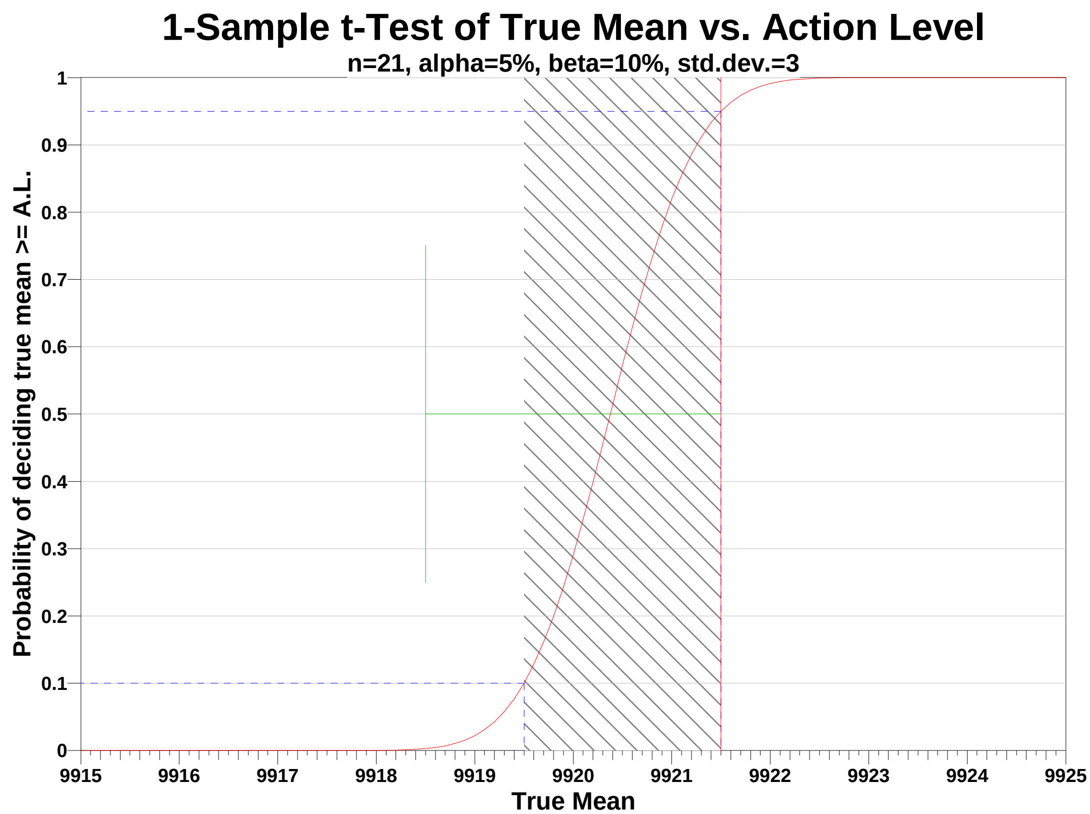
The values of these inputs that result in the calculated number of sampling locations are:

Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	21	3	2	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs change, the number of samples that result in the correct curve changes.



Statistical Assumptions
The assumptions associated with the formulas for computing the number of samples are:
1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis
The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=9921.5		**α=5**		**α=10**		**α=15**	
		s=6	**s=3**	**s=6**	**s=3**	**s=6**	**s=3**
LBGR=90	**β=5**	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1
LBGR=80	**β=5**	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1
LBGR=70	**β=5**	2	2	1	1	1	1

	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $11,500.00, which averages out to a per sample cost of $547.62. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**21 Samples**
Field collection costs		$100.00	$2,100.00
Analytical costs	$400.00	$400.00	$8,400.00
Sum of Field & Analytical costs		**$500.00**	**$10,500.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$11,500.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	1	2	3	4	5	6	7	8	9	10
0	0	11.2	16.9	17.2	17.2	24.7	26.7	27	27.5	29.4
10	29.6	29.6	32.25	34.5	37.8	37.8	40	52.3	53.4	58.3
20	59.8	64.1	68.2	76.1	86.4	88.2	91.2	91.4	95.9	96.5
30	104	119	122	128	134	187	207	208	257.6	305
40	463	569	611	802	812	896				

SUMMARY STATISTICS	
n	46
Min	0
Max	896
Range	896
Mean	159.69
Median	72.15
Variance	50869
StdDev	225.54
Std Error	33.254
Skewness	2.195
Interquartile Range	117.65

Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
0	13.2	17.2	29.6	72.15	147.3	581.6	808.5	896

Outlier Test
Rosner's test for multiple outliers was performed to test whether the most extreme value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

In using Rosner's test to detect up to 1 outlier, a test statistic R_1 is calculated, and compared with a critical value C_1 to test the hypothesis that there is one outlier in the data.

ROSNER'S OUTLIER TEST			
k	**Test Statistic R_k**	**5% Critical Value C_k**	**Significant?**
1	3.231	3.09	Yes

The test statistic 3.231 exceeded the corresponding critical value, therefore that test is significant and we conclude that the most extreme value is an outlier at the 5% significance level.

SUSPECTED OUTLIERS	
1	896

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Rosner's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.642
Shapiro-Wilk 5% Critical Value	0.944

The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the most extreme value, do not appear to follow a normal distribution at the 5% level of significance. Rosner's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

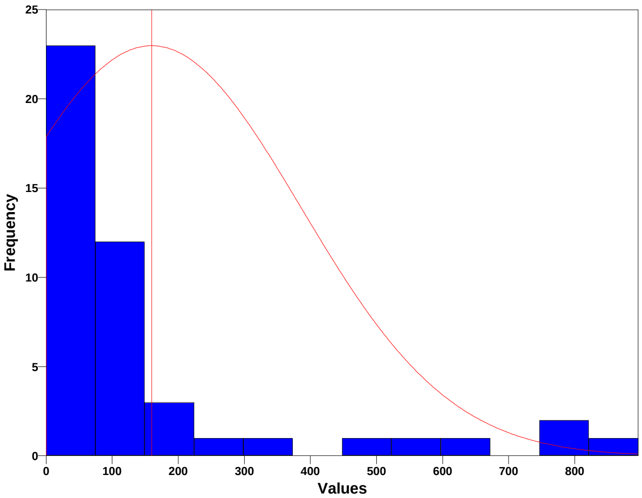
Data Plots
Graphical displays of the data are shown below.

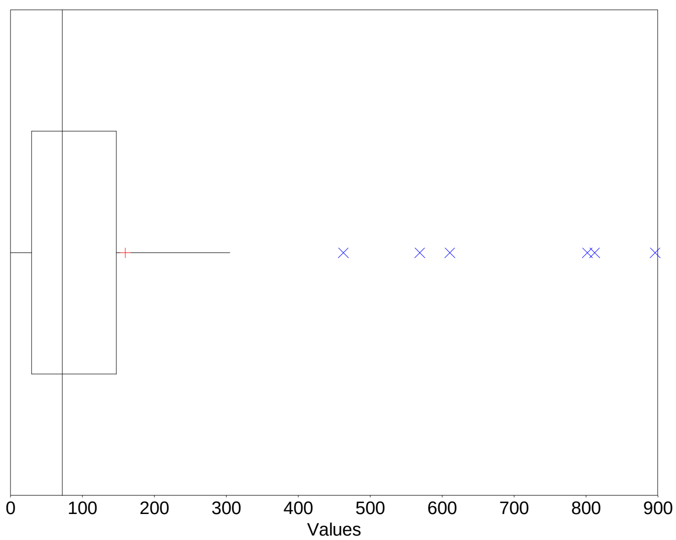
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

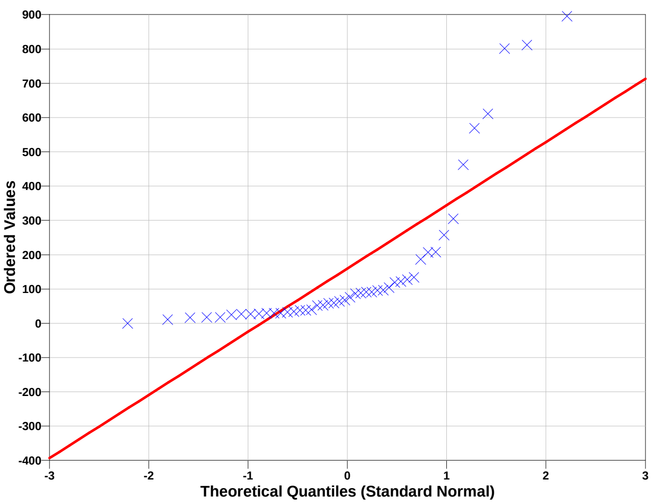
The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5

times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The p^{th} quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests
A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.6439
Shapiro-Wilk 5% Critical Value	0.945

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the

data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean
Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	215.5
95% Non-Parametric (Chebyshev) UCL	304.6

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (304.6) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=46 data,
AL is the action level or threshold (9921.5),
SE is the standard error = (standard deviation) / (square root of n).

This *t* was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=45 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-293.55	1.6794	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
46	29	Reject

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Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679638.466	3083412.561	G-21SD	134	Manual	
679715.315	3083530.019	G-22SD	611	Manual	
679789.831	3083644.936	G-23SD	207	Manual	
679780.111	3083404.025	G-24SD	53.4	Manual	
679854.225	3083519.822	G-25SD	68.2	Manual	
679931.397	3083636.406	G-26SD	257.6	Manual	
679393.438	3082582.947	G-27SD	29.6	Manual	
679470.286	3082698.021	G-28SD	32.25	Manual	
679543.314	3082816.106	G-29SD	34.5	Manual	
679619.124	3082932.898	G-30SD	17.2	Manual	
679693.405	3083047.549	G-31SD	16.9	Manual	
679768.226	3083162.727	G-32SD	52.3	Manual	
679841.774	3083280.235	G-33SD	91.2	Manual	
679917.766	3083397.416	G-34SD	11.2	Manual	
679994.207	3083513.447	G-35SD	40	Manual	
679530.943	3082575.448	G-36SD	119	Manual	
679606.684	3082692.383	G-37SD	187	Manual	
679681.465	3082807.799	G-38SD	122	Manual	
679756.109	3082922.939	G-39SD	37.8	Manual	
679832.158	3083041.871	G-40SD	27.5	Manual	
679906.421	3083156.754	G-41SD	37.8	Manual	
679982.277	3083273.065	G-42SD	26.7	Manual	
680056.981	3083387.33	G-43SD	463	Manual	
680132.65	3083505.456	G-44SD	88.2	Manual	
679597.188	3082450.923	G-45SD	96.5	Manual	
679671.317	3082565.925	G-46SD	896	Manual	
679745.982	3082681.386	G-47SD	64.1	Manual	
679822.074	3082799.575	G-48SD	812	Manual	
679896.612	3082915.666	G-49SD	24.7	Manual	
679971.215	3083030.792	G-50SD	58.3	Manual	
680046.783	3083146.999	G-51SD	76.1	Manual	
680123.432	3083263.001	G-52SD	95.9	Manual	
680198.058	3083379.815	G-53SD	104	Manual	
680185.412	3083138.847	G-54SD	128	Manual	
680260.421	3083254.807	G-55SD	569	Manual	
680335.97	3083372.02	G-56SD	86.4	Manual	
680022.008	3083237.472	J-44SD	29.4	Manual	
680047.095	3083215.942	J-45SD	91.4	Manual	
679887.433	3082812.936	J-46SD	305	Manual	
679521.779	3082672.022	J-54SD	208	Manual	
679590.092	3082773.184	J-55SD	59.8	Manual	
679763.399	3083050.055	J-56SD	27	Manual	
680108.013	3083101.352	J-57SD	802	Manual	
680413.831	3083297.013	J-58SD	96	Manual	

Random sampling locations for comparing a mean with a fixed threshold (parametric)

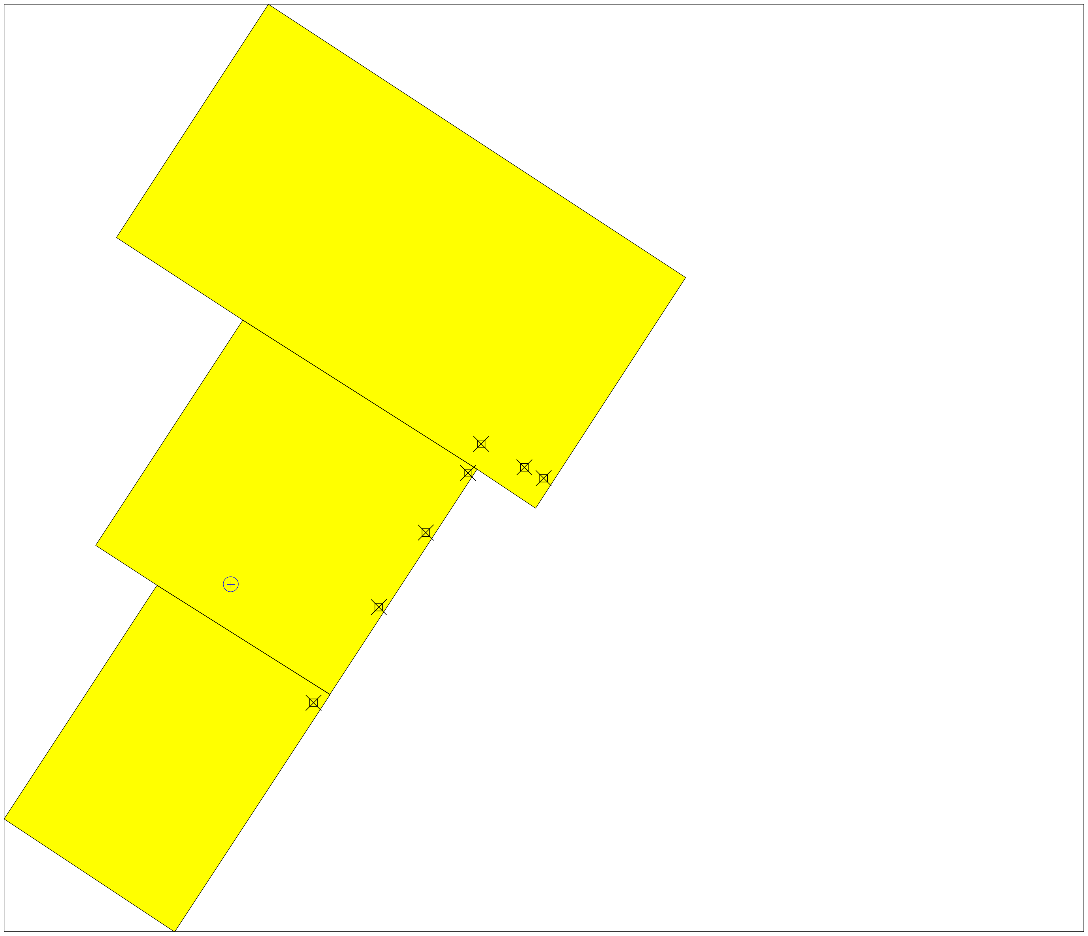
Summary

This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	2
Number of samples on map [a]	8
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$2,000.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	Y Coord	Label	Value	Type	Historical
680077.3540	3083115.5330	J-50S	13.7	Manual	T
680141.8730	3083080.8800	J-52S	8.9	Manual	T
680170.5600	3083064.6740	J-53S	17.5	Manual	T

Area: Area 2					
X Coord	Y Coord	Label	Value	Type	Historical
679924.8150	3082872.3490	J-47S	35.8	Manual	T
679994.9690	3082983.5100	J-48S	10.2	Manual	T
680057.6580	3083072.0750	J-49S	18.2	Manual	T
679704.1121	3082906.1307	J-51S	11.9	Random	

Area: Area 3					
X Coord	Y Coord	Label	Value	Type	Historical
679827.1150	3082729.7460	J-51S	11.9	Manual	T

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null

hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

The values of these inputs that result in the calculated number of sampling locations are:

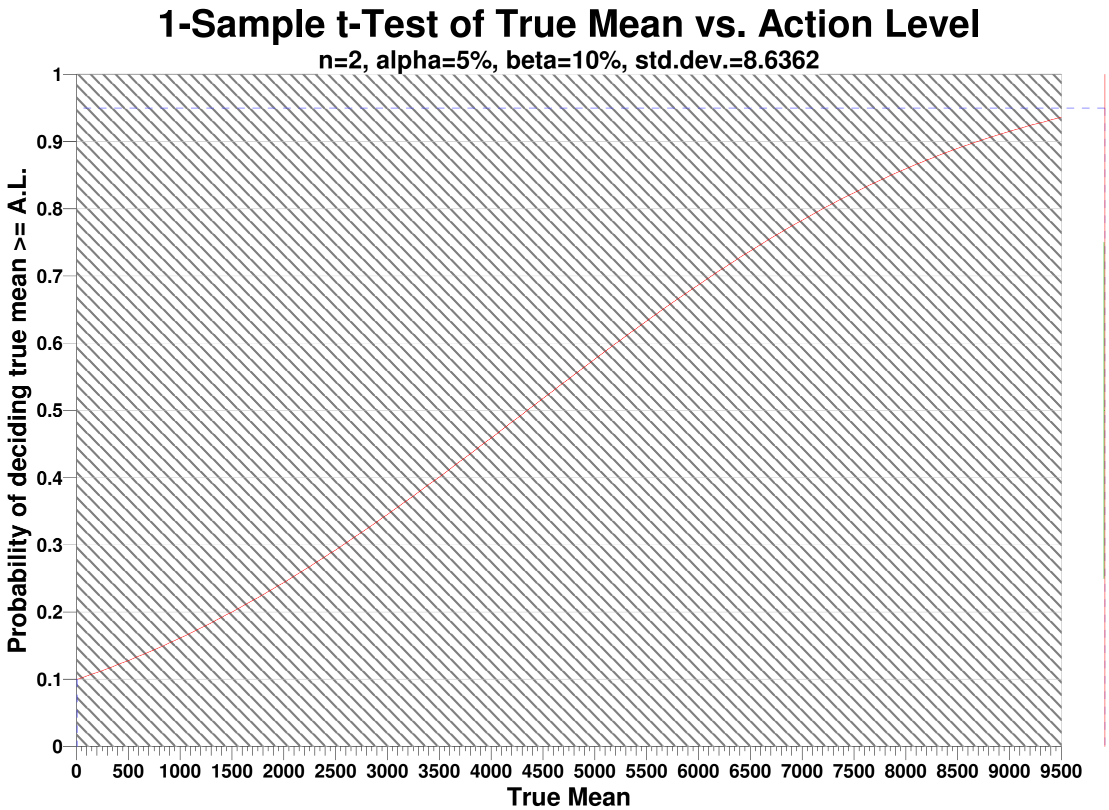
Analyte	n	Parameter					
		S	Δ	α	β	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	2	8.6362	9913.5	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs

change, the number of samples that result in the correct curve changes.



Statistical Assumptions

The assumptions associated with the formulas for computing the number of samples are:

1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis

The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=9921.5		α=5		α=10		α=15	
		s=17.2724	s=8.6362	s=17.2724	s=8.6362	s=17.2724	s=8.6362
LBGR=90	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1
LBGR=80	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

LBGR=70	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $2,000.00, which averages out to a per sample cost of $1,000.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**2 Samples**
Field collection costs		$100.00	$200.00
Analytical costs	$400.00	$400.00	$800.00
Sum of Field & Analytical costs		**$500.00**	**$1,000.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$2,000.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	1	2	3	4	5	6	7	8	9	10
0	8.9	10.2	11.9	11.9	13.7	17.5	18.2	35.8		

SUMMARY STATISTICS								
n	8							
Min	8.9							
Max	35.8							
Range	26.9							
Mean	16.012							
Median	12.8							
Variance	74.584							
StdDev	8.6362							
Std Error	3.0534							
Skewness	2.0859							
Interquartile Range	7.4							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
8.9	8.9	8.9	10.63	12.8	18.02	35.8	35.8	35.8

Outlier Test
Dixon's extreme value test was performed to test whether the lowest value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

DIXON'S OUTLIER TEST	
Dixon Test Statistic	0.13978
Dixon 5% Critical Value	0.554

The calculated test statistic does not exceed the critical value, so the test cannot reject the null hypothesis that there are no outliers in the data, and concludes that the minimum value 8.9 is not an outlier at the 5% significance level.

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Dixon's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.7492
Shapiro-Wilk 5% Critical Value	0.803

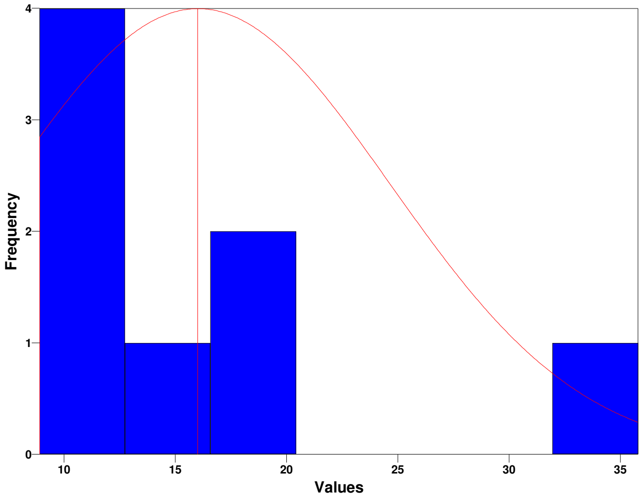
The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the minimum value 8.9, do not appear to follow a normal distribution at the 5% level of significance. Dixon's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

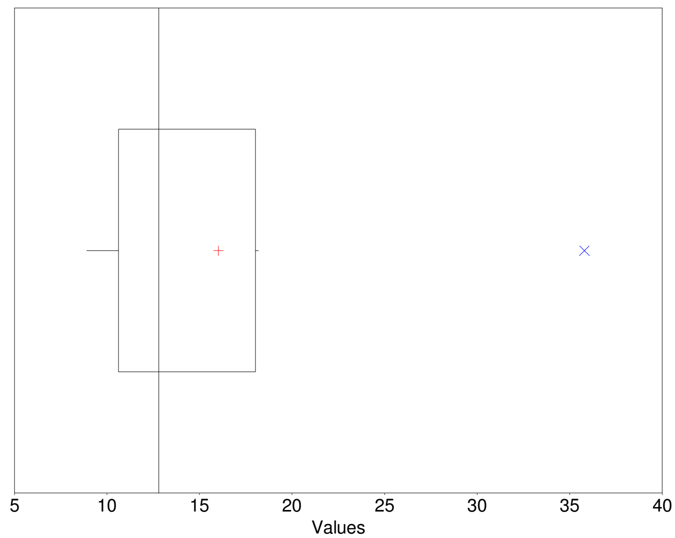
Data Plots
Graphical displays of the data are shown below.

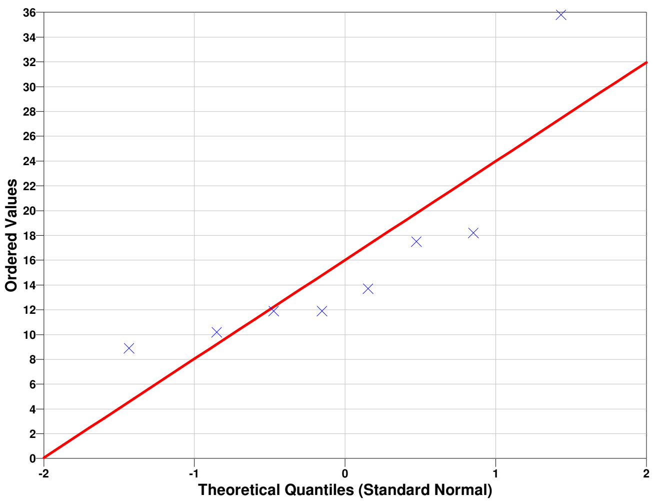
The Histogram is a plot of the fraction of the n observed data that fall within specified data "bins." A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The pth quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.7576
Shapiro-Wilk 5% Critical Value	0.818

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	21.8

95% Non-Parametric (Chebyshev) UCL	29.32

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (29.32) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=8 data,
AL is the action level or threshold (9921.5),
SE is the standard error = (standard deviation) / (square root of n).

This t was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=7 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-3244.1	1.8946	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
8	6	Reject

This report was automatically produced* by Visual Sample Plan (VSP) software version 5.000.
Software and documentation available at http://dqo.pnl.gov/vsp

* - The report contents may have been modified or reformatted by end-user of software.

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	35.8	Manual	
679994.969	3082983.51	J-48S	10.2	Manual	
680057.658	3083072.075	J-49S	18.2	Manual	
680077.354	3083115.533	J-50S	13.7	Manual	
679827.115	3082729.746	J-51S	11.9	Manual	
680141.873	3083080.88	J-52S	8.9	Manual	
680170.56	3083064.674	J-53S	17.5	Manual	

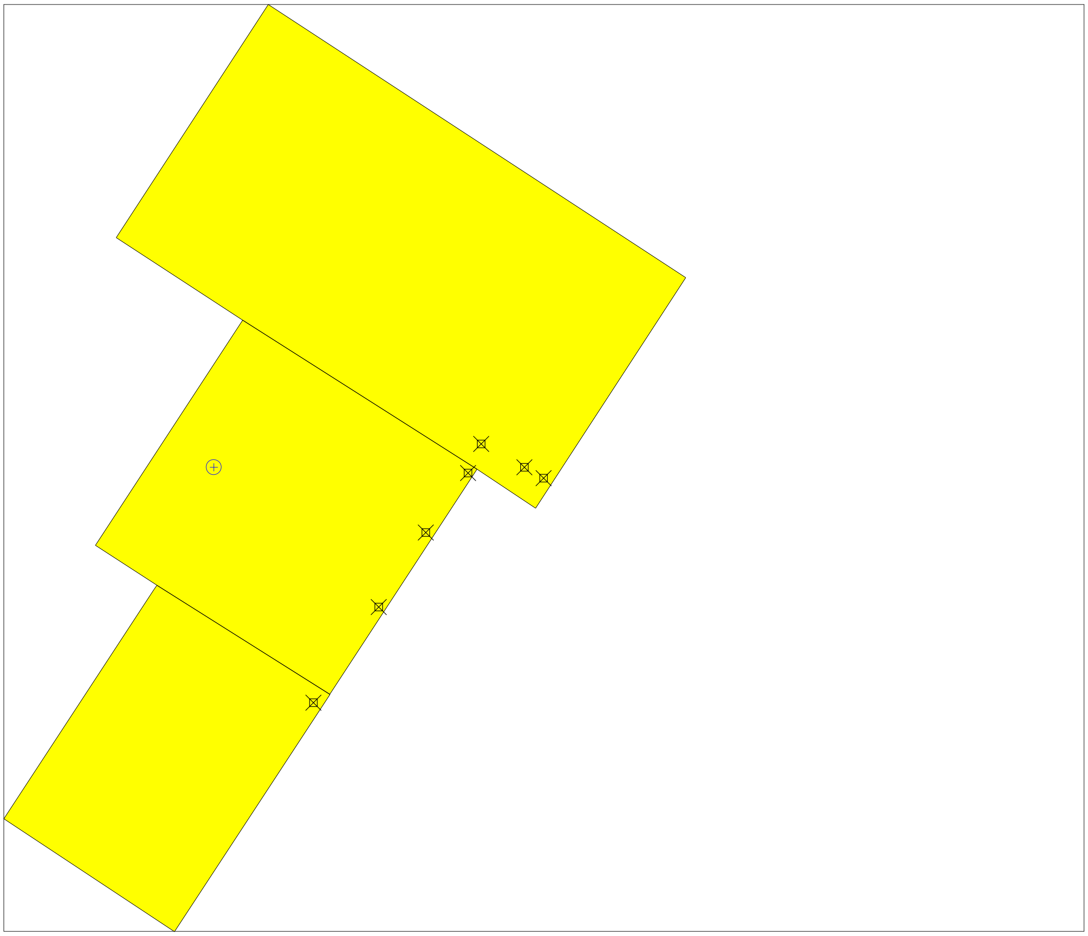
Random sampling locations for comparing a mean with a fixed threshold (parametric)

Summary
This report summarizes the sampling design used, associated statistical assumptions, as well as general guidelines for conducting post-sampling data analysis. Sampling plan components presented here include how many sampling locations to choose and where within the sampling area to collect those samples. The type of medium to sample (i.e., soil, groundwater, etc.) and how to analyze the samples (in-situ, fixed laboratory, etc.) are addressed in other sections of the sampling plan.

The following table summarizes the sampling design developed. A figure that shows sampling locations in the field and a table that lists sampling location coordinates are also provided below.

SUMMARY OF SAMPLING DESIGN	
Primary Objective of Design	Compare a site mean to a fixed threshold
Type of Sampling Design	Parametric
Sample Placement (Location) in the Field	Simple random sampling
Working (Null) Hypothesis	The mean value at the site exceeds the threshold
Formula for calculating number of sampling locations	Student's t-test
Calculated total number of samples	2
Number of samples on map [a]	8
Number of selected sample areas [b]	3
Specified sampling area [c]	602131.68 m^2
Total cost of sampling [d]	$2,000.00

[a] This number may differ from the calculated number because of 1) grid edge effects, 2) adding judgment samples, or 3) selecting or unselecting sample areas.
[b] The number of selected sample areas is the number of colored areas on the map of the site. These sample areas contain the locations where samples are collected.
[c] The sampling area is the total surface area of the selected colored sample areas on the map of the site.
[d] Including measurement analyses and fixed overhead costs. See the Cost of Sampling section for an explanation of the costs presented here.



Area: Area 1					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
680077.3540	3083115.5330	J-50S	23.9	Manual	T
680141.8730	3083080.8800	J-52S	32.8	Manual	T
680170.5600	3083064.6740	J-53S	279	Manual	T

Area: Area 2					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679924.8150	3082872.3490	J-47S	346	Manual	T
679994.9690	3082983.5100	J-48S	44	Manual	T
680057.6580	3083072.0750	J-49S	32.9	Manual	T
679678.8319	3083081.0582	J-51S	66.6	Random	

Area: Area 3					
X Coord	**Y Coord**	**Label**	**Value**	**Type**	**Historical**
679827.1150	3082729.7460	J-51S	66.6	Manual	T

Primary Sampling Objective
The primary purpose of sampling at this site is to compare a mean value with a fixed threshold. The working hypothesis (or 'null' hypothesis) is that the mean value at the site is equal to or exceeds the threshold. The alternative hypothesis is that the mean value is less than the threshold. VSP calculates the number of samples required to reject the null

hypothesis in favor of the alternative hypothesis, given a selected sampling approach and inputs to the associated equation.

Selected Sampling Approach
A parametric random sampling approach was used to determine the number of samples and to specify sampling locations. A parametric formula was chosen because the conceptual model and historical information (e.g., historical data from this site or a very similar site) indicate that parametric assumptions are reasonable. These assumptions will be examined in post-sampling data analysis.

Both parametric and non-parametric approaches rely on assumptions about the population. However, non-parametric approaches typically require fewer assumptions and allow for more uncertainty about the statistical distribution of values at the site. The trade-off is that if the parametric assumptions are valid, the required number of samples is usually less than the number of samples required by non-parametric approaches.

Locating the sample points randomly provides data that are separated by many distances, whereas systematic samples are all equidistant apart. Therefore, random sampling provides more information about the spatial structure of the potential contamination than systematic sampling does. As with systematic sampling, random sampling also provides information regarding the mean value, but there is the possibility that areas of the site will not be represented with the same frequency as if uniform grid sampling were performed.

Number of Total Samples: Calculation Equation and Inputs
The equation used to calculate the number of samples is based on a Student's t-test. For this site, the null hypothesis is rejected in favor of the alternative hypothesis if the sample mean is sufficiently smaller than the threshold. The number of samples to collect is calculated so that 1) there will be a high probability ($1-\beta$) of rejecting the null hypothesis if the alternative hypothesis is true and 2) a low probability (α) of rejecting the null hypothesis if the null hypothesis is true.

The formula used to calculate the number of samples is:

$$n = \frac{S^2}{\Delta^2}\left(Z_{1-\alpha} + Z_{1-\beta}\right)^2 + 0.5Z_{1-\alpha}^2$$

where
n is the number of samples,
S is the estimated standard deviation of the measured values including analytical error,
Δ is the width of the gray region,
α is the acceptable probability of incorrectly concluding the site mean is less than the threshold,
β is the acceptable probability of incorrectly concluding the site mean exceeds the threshold,
$Z_{1-\alpha}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\alpha}$ is $1-\alpha$,
$Z_{1-\beta}$ is the value of the standard normal distribution such that the proportion of the distribution less than $Z_{1-\beta}$ is $1-\beta$.

The values of these inputs that result in the calculated number of sampling locations are:

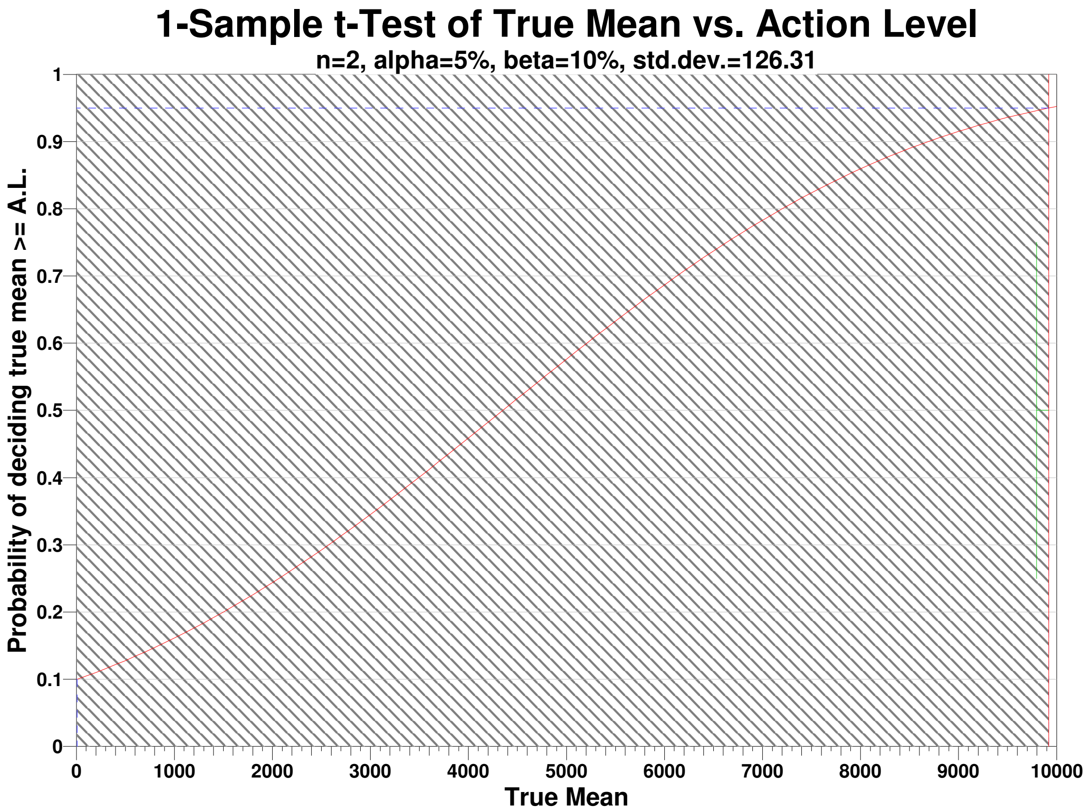
Analyte	n	Parameter					
		S	**Δ**	**α**	**β**	$Z_{1-\alpha}$ [a]	$Z_{1-\beta}$ [b]
	2	126.31	9913.5	0.05	0.1	1.64485	1.28155

[a] This value is automatically calculated by VSP based upon the user defined value of α.
[b] This value is automatically calculated by VSP based upon the user defined value of β.

The following figure is a performance goal diagram, described in EPA's QA/G-4 guidance (EPA, 2000). It shows the probability of concluding the sample area is dirty on the vertical axis versus a range of possible true mean values for the site on the horizontal axis. This graph contains all of the inputs to the number of samples equation and pictorially represents the calculation.

The red vertical line is shown at the threshold (action limit) on the horizontal axis. The width of the gray shaded area is equal to Δ; the upper horizontal dashed blue line is positioned at $1-\alpha$ on the vertical axis; the lower horizontal dashed blue line is positioned at β on the vertical axis. The vertical green line is positioned at one standard deviation below the threshold. The shape of the red curve corresponds to the estimates of variability. The calculated number of samples results in the curve that passes through the lower bound of Δ at β and the upper bound of Δ at $1-\alpha$. If any of the inputs

change, the number of samples that result in the correct curve changes.



Statistical Assumptions
The assumptions associated with the formulas for computing the number of samples are:
1. the sample mean is normally distributed (this happens if the data are roughly symmetric and the sample size is 30 or more; for skewed data sets, additional samples are required for the sample mean to be normally distributed),
2. the variance estimate, S^2, is reasonable and representative of the population being sampled,
3. the population values are not spatially or temporally correlated, and
4. the sampling locations will be selected randomly.

The first three assumptions will be assessed in a post data collection analysis. The last assumption is valid because the sample locations were selected using a random process.

Sensitivity Analysis
The sensitivity of the calculation of number of samples was explored by varying the standard deviation, lower bound of gray region (% of action level), beta (%), probability of mistakenly concluding that μ > action level and alpha (%), probability of mistakenly concluding that μ < action level and examining the resulting changes in the number of samples. The following table shows the results of this analysis.

Number of Samples							
AL=9921.5		α=5		α=10		α=15	
		s=252.62	s=126.31	s=252.62	s=126.31	s=252.62	s=126.31
LBGR=90	β=5	3	2	2	1	2	1
	β=10	2	2	2	1	1	1
	β=15	2	2	2	1	1	1
LBGR=80	β=5	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

LBGR=70	**β=5**	2	2	1	1	1	1
	β=10	2	2	1	1	1	1
	β=15	2	2	1	1	1	1

s = Standard Deviation
LBGR = Lower Bound of Gray Region (% of Action Level)
β = Beta (%), Probability of mistakenly concluding that μ > action level
α = Alpha (%), Probability of mistakenly concluding that μ < action level
AL = Action Level (Threshold)

Cost of Sampling
The total cost of the completed sampling program depends on several cost inputs, some of which are fixed, and others that are based on the number of samples collected and measured. Based on the numbers of samples determined above, the estimated total cost of sampling and analysis at this site is $2,000.00, which averages out to a per sample cost of $1,000.00. The following table summarizes the inputs and resulting cost estimates.

COST INFORMATION			
Cost Details	**Per Analysis**	**Per Sample**	**2 Samples**
Field collection costs		$100.00	$200.00
Analytical costs	$400.00	$400.00	$800.00
Sum of Field & Analytical costs		**$500.00**	**$1,000.00**
Fixed planning and validation costs			$1,000.00
Total cost			**$2,000.00**

Data Analysis
The following data points were entered by the user for analysis.

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	23.9	32.8	32.9	44	66.6	66.6	279	346		

SUMMARY STATISTICS								
n	8							
Min	23.9							
Max	346							
Range	322.1							
Mean	111.47							
Median	55.3							
Variance	15954							
StdDev	126.31							
Std Error	44.657							
Skewness	1.4621							
Interquartile Range	193.08							
Percentiles								
1%	**5%**	**10%**	**25%**	**50%**	**75%**	**90%**	**95%**	**99%**
23.9	23.9	23.9	32.82	55.3	225.9	346	346	346

Outlier Test
Dixon's extreme value test was performed to test whether the lowest value is a statistical outlier. The test was conducted at the 5% significance level.

Data should not be excluded from analysis solely on the basis of the results of this or any other statistical test. If any values are flagged as possible outliers, further investigation is recommended to determine whether there is a plausible explanation that justifies removing or replacing them.

DIXON'S OUTLIER TEST	
Dixon Test Statistic	0.034888
Dixon 5% Critical Value	0.554

The calculated test statistic does not exceed the critical value, so the test cannot reject the null hypothesis that there are no outliers in the data, and concludes that the minimum value 23.9 is not an outlier at the 5% significance level.

A normal distribution test indicated that the data do not appear to be normally distributed, so further investigation is recommended before using the results of this test. Because Dixon's test can be used only when the data without the suspected outlier are approximately normally distributed, a Shapiro-Wilk test for normality was performed at a 5% significance level.

NORMAL DISTRIBUTION TEST (excluding outliers)	
Shapiro-Wilk Test Statistic	0.7241
Shapiro-Wilk 5% Critical Value	0.803

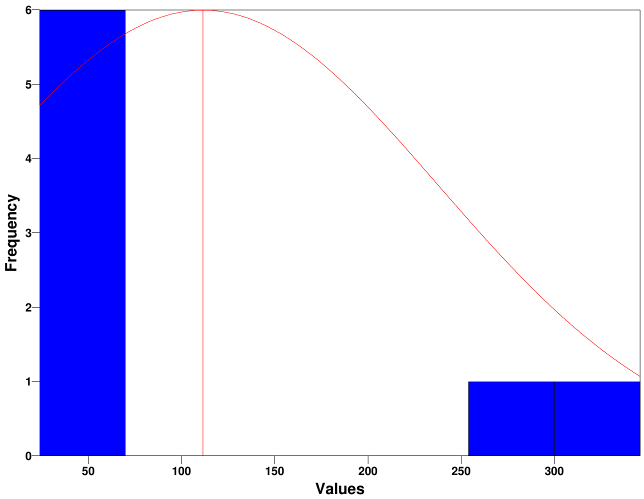
The calculated Shapiro-Wilk test statistic is less than the 5% Shapiro-Wilk critical value, so the test rejects the hypothesis that the data are normal and concludes that the data, excluding the minimum value 23.9, do not appear to follow a normal distribution at the 5% level of significance. Dixon's test may not be appropriate if the assumption of normally distributed data is not justified for this data set. Examine the Q-Q plot displayed below to further assess the normality of the data.

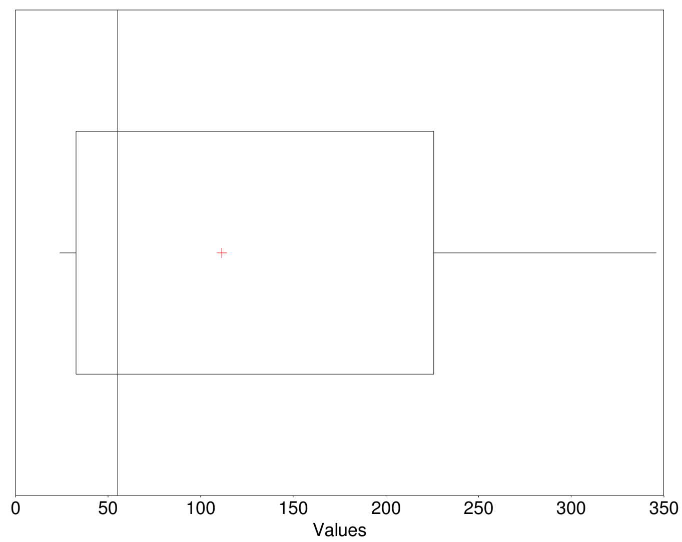
Data Plots
Graphical displays of the data are shown below.

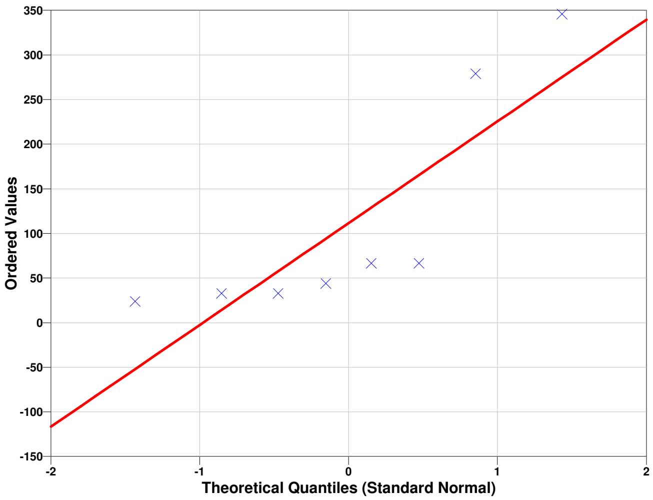
The Histogram is a plot of the fraction of the n observed data that fall within specified data “bins.” A histogram is generated by dividing the x axis (range of the observed data values) into "bins" and displaying the number of data in each bin as the height of a bar for the bin. The area of the bar is the fraction of the n data values that lie within the bin. The sum of the fractions for all bins equals one. A histogram is used to assess how the n data are distributed (spread) over their range of values. If the histogram is more or less symmetric and bell shaped, then the data may be normally distributed.

The Box and Whiskers plot is composed of a central box divided by a line, and with two lines extending out from the box, called the "whiskers". The line through the box is drawn at the median of the n data observed. The two ends of the box represent the 25th and 75th percentiles of the n data values, which are also called the lower and upper quartiles, respectively, of the data set. The sample mean (mean of the n data) is shown as a "+" sign. The upper whisker extends to the largest data value that is less than the upper quartile plus 1.5 times the interquartile range (upper quartile minus the lower quartile). The lower whisker extends to the smallest data value that is greater than the lower quartile minus 1.5 times the interquartile range. Extreme data values (greater or smaller than the ends of the whiskers) are plotted individually as blue Xs. A Box and Whiskers plot is used to assess the symmetry of the distribution of the data set. If the distribution is symmetrical, the box is divided into two equal halves by the median, the whiskers will be the same length, and the number of extreme data points will be distributed equally on either end of the plot.

The Q-Q plot graphs the quantiles of a set of n data against the quantiles of a specific distribution. We show here only the Q-Q plot for an assumed normal distribution. The pth quantile of a distribution of data is the data value, x_p, for which a fraction p of the distribution is less than x_p. If the data plotted on the normal distribution Q-Q plot closely follow a straight line, even at the ends of the line, then the data may be assumed to be normally distributed. If the data points deviate substantially from a linear line, then the data are not normally distributed.







For more information on these plots consult Guidance for Data Quality Assessment, EPA QA/G-9, pgs 2.3-1 through 2.3-12. (http://www.epa.gov/quality/qa-docs.html).

Tests

A goodness-of-fit test was performed to test whether the data set had been drawn from an underlying normal distribution. The Shapiro-Wilk (SW) test was used to test the null hypothesis that the data are normally distributed. The test was conducted at the 5% significance level, i.e., the probability the test incorrectly rejects the null hypothesis was set at 0.05.

NORMAL DISTRIBUTION TEST	
Shapiro-Wilk Test Statistic	0.7019
Shapiro-Wilk 5% Critical Value	0.818

The calculated SW test statistic is less than the 5% Shapiro-Wilk critical value, so we can reject the hypothesis that the data are normal, or in other words the data do not appear to follow a normal distribution at the 5% level of significance. The Q-Q plot displayed above should be used to further assess the normality of the data.

Upper Confidence Limit on the True Mean

Two methods were used to compute the upper confidence limit (UCL) on the mean. The first is a parametric method that assumes a normal distribution. The second is the Chebyshev method, which requires no distributional assumption.

UCLs ON THE MEAN	
95% Parametric UCL	196.1

95% Non-Parametric (Chebyshev) UCL	306.1

Because the data do not appear to be normally distributed according to the goodness-of-fit test performed above, the non-parametric UCL (306.1) may be a more accurate upper confidence limit on the true mean.

One-Sample t-Test
A one-sample t-test was performed to compare the sample mean to the action level. The null hypothesis used is that the true mean equals or exceeds the action level (AL). The t-test was conducted at the 5% significance level. The sample value *t* was computed using the following equation:

$$t = \frac{\bar{x} - AL}{SE}$$

where
x is the sample mean of the n=8 data,
AL is the action level or threshold (9921.5),
SE is the standard error = (standard deviation) / (square root of n).

This *t* was then compared with the critical value $t_{0.95}$, where $t_{0.95}$ is the value of the t distribution with n-1=7 degrees of freedom for which the proportion of the distribution to the left of $t_{0.95}$ is 0.95. The null hypothesis will be rejected if $t < -t_{0.95}$.

ONE-SAMPLE t-TEST		
t-statistic	**Critical Value $t_{0.95}$**	**Null Hypothesis**
-219.67	1.8946	Reject

The test rejected the null hypothesis that the mean value at the site exceeds the threshold, therefore conclude the true mean is less than the threshold.

Because the data do not appear to be normally distributed, the MARSSIM Sign Test might be preferred over the One Sample t-Test. The following table represents the results of the MARSSIM Sign Test using the current data:

MARSSIM Sign Test		
Test Statistic (S+)	**95% Critical Value**	**Null Hypothesis**
8	6	Reject

Area: Area 1

X Coord	Y Coord	Label	Value	Type	Historical
679924.815	3082872.349	J-47S	346	Manual	
679994.969	3082983.51	J-48S	44	Manual	
680057.658	3083072.075	J-49S	32.9	Manual	
680077.354	3083115.533	J-50S	23.9	Manual	
679827.115	3082729.746	J-51S	66.6	Manual	
680141.873	3083080.88	J-52S	32.8	Manual	
680170.56	3083064.674	J-53S	279	Manual	